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# GEOLOGY AND GEOMORPHOLOGY OF THE LAKE TAHOE REGION

## A Guide for Planning

*Prepared for*

*Tahoe Regional Planning Agency*

*and*

*Forest Service, U. S. Department of Agriculture*

**South Lake Tahoe, California**

**September 1971**

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# ACKNOWLEDGMENTS

Establishment of the Tahoe Regional Planning Agency was consented to by the Congress through enactment of Public Law 91-148. On March 19, 1970, the governors of Nevada and California signed the Proclamation that proclaimed creation of the Tahoe Regional Planning Agency. Since the authorized staff of the Agency was small, it enlisted help from several committees composed of technical specialists and other citizens concerned with resource conservation and orderly development of the Tahoe environmental resources.

The planning effort has been aided greatly by generous cooperation from numerous federal, state, county, and municipal agencies and from several colleges and interested private individuals. Cooperating agencies included:

**Federal:**

Department of Agriculture: Forest Service; Soil Conservation Service

Department of Commerce: Environmental Science Services Administration

Department of Defense: Army Corps of Engineers

Department of Interior: The Bureaus of Mines, Outdoor Recreation, Reclamation, Sport Fisheries and Wildlife; Federal Water Quality Administration; and the Geological Survey

Department of Transportation: Coast Guard; Federal Highway Administration; Federal Aviation Administration

**State:**

California: The Resources Agency of California

Nevada: The Nevada Department of Conservation and Natural Resources

**County and Municipal:**

Carson City, Douglas, and Washoe Counties, Nevada; El Dorado and Placer Counties and City of South Lake Tahoe, California

**Schools:**

Foresta Institute; Sacramento State College; Tahoe College; University of California at Berkeley and Davis; University of Nevada; Desert Research Institute

Any publication that compiles and presents information from so large and disparate a group of contributors as this one does is susceptible to error, inconsistency, and omission. Sustained effort has been made to avoid these flaws; but if it has failed occasionally, the reader's forbearance is humbly solicited.

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The paper titled "Geology for Land Use Planning in the Lake Tahoe Basin" was prepared by Robert A. Matthews and John L. Burnett, geologists of the California Department of Conservation, Division of Mines and Geology, Sacramento.

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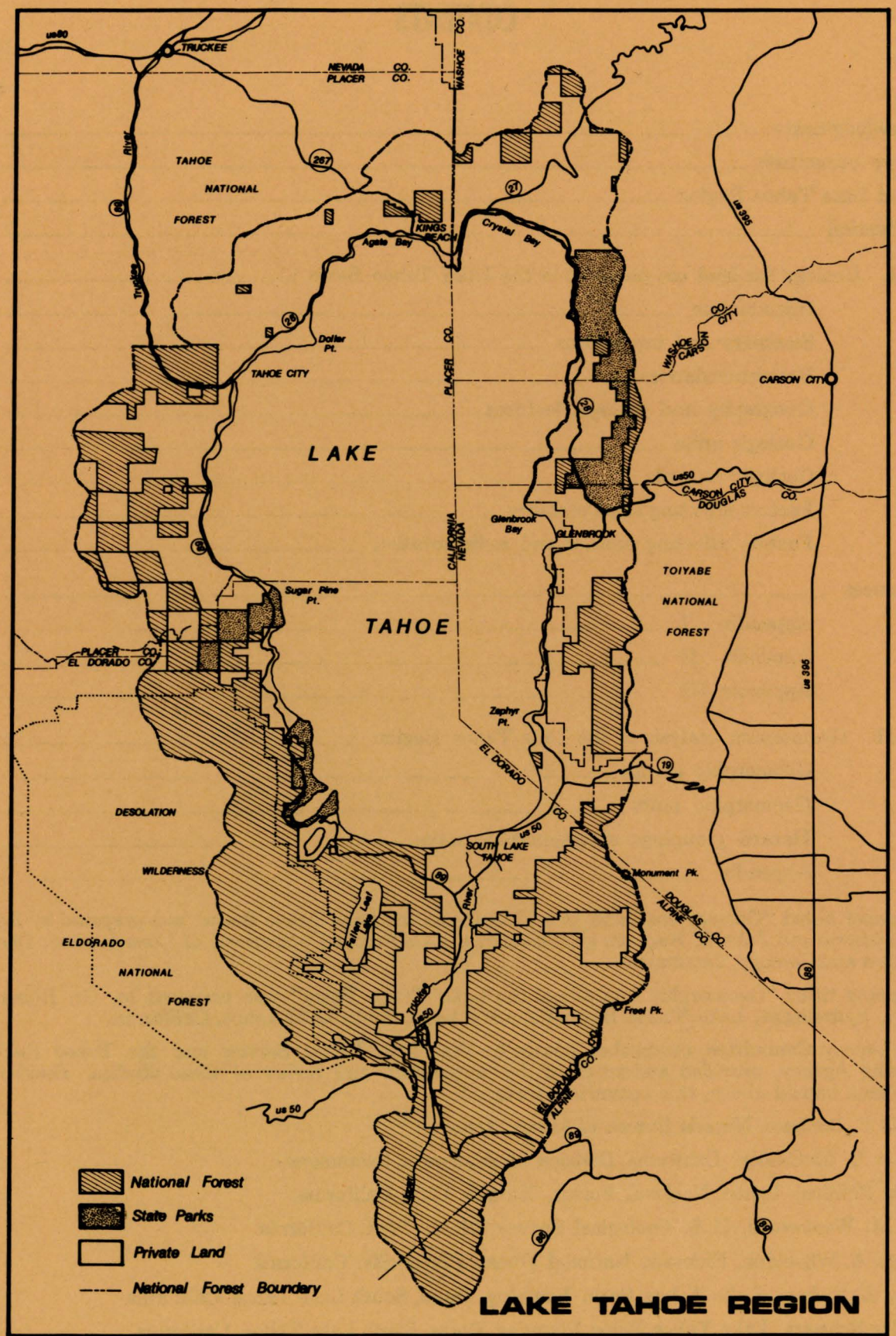
us80
TRUCKEE
NEVADA CO.
PLACER CO.
WASHOE CO.
Truckee River
TAHOE NATIONAL FOREST
267
28
Tahoe
KINGS BEACH
Agate Bay
Crystal Bay
21
us 395
Dollar Pt.
TAHOE CITY
PLACER CO.
WASHOE CO.
CARSON CITY
CARSON CITY
LAKE
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CARSON CITY
DOUGLAS CO.
Glenbrook Bay
GLENBROOK
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NEVADA
TOIYABE NATIONAL FOREST
Sugar Pine Pt.
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LAKE TAHOE REGION

# INTRODUCTION

## General Features of the Lake Tahoe Planning Area

Lake Tahoe and the mountainous timber-covered basin immediately surrounding it provide one of the most beautiful environments in the Sierra Nevada and in the nation. The Lake itself, an irregular oval about 22 miles long by 12 miles wide, covers 191 square miles; it occupies a deep depression between crests of the Sierra Nevada and Carson ranges. Since its surface is about 6,225 feet above mean sea level, Lake Tahoe is one of the largest high-altitude lakes in the world. The clarity and purity of its water are outstanding. In fact, protection of quality of the water in Lake Tahoe is a primary objective for effective control of the region's environment.

The spectacular scenery of the Lake Tahoe Region results from unique geological conditions that prevailed when the lake was formed. The basement rock is predominantly granite related to the rocks found throughout the Sierra Nevada. On the other hand, the geologic structure—the faulting that produced the lake basin itself—is related to the Basin Ranges that extend eastward from the Sierra to the Wasatch Range in Utah. The Lake was formed by a natural dam—a great pile of andesitic mudflow breccia—across the north outlet.

Lake Tahoe is on the eastern boundary of that part of the Sierra Nevada that was extensively glaciated during the Pleistocene epoch. Huge valley glaciers moved down canyons along the western side of the lake, scouring away loose rock and building up great piles of morainal debris. Along the eastern side, glaciers developed only on the shaded side of the highest peaks; so most of this area was not glaciated. This accounts for the subdued rolling topography typical of the Carson Range, as contrasted to the rugged Sierran crest on the west side of the basin.

Climate of the region is strongly influenced by topography. Marine air from the Pacific Ocean, 150 miles to the west, drops its moisture (mostly as snow) as it rises over the crest of the Sierra. Average annual precipitation ranges from more than 50 inches on the western side of the region to about 25 inches along much of the eastern shoreline. The Weather Bureau at Tahoe City, on the west side, reports long-term average snowfall of 213 inches. The fairly long summers are comparatively cool; mean maximum temperature at Tahoe City in July over a 50-year period was 78°F. Winters are cold but seldom severe; mean daily minimum temperature for January over the same period was 17°F. The high elevation and cool temperatures result in a short growing season—an average of only 70 to 120 frost-free days per year at various points near the Lake.

Vegetation includes desert, montane, and alpine species typical of the eastern slopes of the Sierra. Pine and fir forests were heavily logged between 1860 and 1900 when demand for lumber and props for the Nevada silver mines was high. Even so, today the region has good stands of conifers between the Lake level and 9,000 feet, plus considerable areas covered by chaparral and other brush. On fairly level open areas that have a few inches of soil, grasses and other herbage flourish during the short growing season.

Numerous species of wildlife inhabit the Lake Tahoe Region. Deer, bear, mountain lion, coyote, rabbit, raccoon, and several rodents are common. Land birds and waterfowl are present in small numbers consistent with available habitat. Heavy commercial fishing in the Lake around 1900 depleted native populations of cutthroat trout and whitefish, but kokanee salmon and several species of fish stocked from state hatcheries provide good recreational fishing today. Numerous tributary streams also provide sport fishing.

Soils are generally shallow and highly erodible—easily disturbed and slow to stabilize—but the soil is fairly deep in some bottom lands and glacial debris areas. The varied climate and highly erodible soils combine to make the Lake Tahoe Region a fragile environment. Hence the ecological balance is easily upset. Whenever vegetation is removed, it is not soon replaced. Erosion by wind and water is a constant hazard; it damages pristine features of the Lake, including the spawning areas of native fish.

## Changing Environment

Before the white man invaded this area about the middle of the 1800's, the somewhat nomadic Washo Indian tribe inhabited it. Their name for the Lake, "Tahoe," has been variously translated as

"big water," "high water," or "water in a high place." The first recorded white visitors were John Fremont's exploring party (1844); they were soon followed by the Forty-niners and other western migrants and adventurers.

During most of the following 100 years, Lake Tahoe was the summer recreation area for wealthy Californians, mostly from San Francisco and the Sacramento Valley. The few summer resorts, scattered stores, service stations, and restaurants hardly marred the natural beauty of the Region.

Soon after World War II all this began to change. With increased general affluence, steadily and rapidly increasing numbers of vacationers began to visit the area; their visits gradually extended the "season" from the summer to the full year. Establishment of year-round casinos at Stateline in 1955 and the phenomenal growth of winter sports added to the influx of both visitors and residents. By unofficial count in 1965, the Region had nearly 29,000 yearlong residents—more than double the 1960 federal census figure. Present projections anticipate more than 50,000 residents by 1980 and an added summer population topping 250,000.

These projected increases in resident and transient populations will inevitably multiply and intensify the environmental problems that already are plaguing the area. Hence the crucial need for planning orderly development that can be sustained by the natural capacities of the region.

**Administrative and Governmental Responsibility**

The planning area established by the Bi-State Planning Compact between the States of California and Nevada is a basin covering 327,878 acres including the 122,628 acres of lake surface. Governmental jurisdiction over land in the Lake Tahoe Planning Area is complex (table 1). The area is divided between California (Placer, El Dorado, and Alpine Counties) and Nevada (Washoe and Douglas Counties and Carson City). This division of governmental responsibility makes it difficult to coordinate the administration of government in the area in the interest of protecting the environment.

Table 1.—**Land acreage, by jurisdiction, Lake Tahoe Regional Planning Area, February 1971**

| Jurisdiction | Gross Acreage | Federal Land Acreage[1] | State Park Acreage | Private Land Acreage |
|---|---|---|---|---|
| Federal: | | | | |
| Eldorado N. F. | 85,518 | | | |
| Tahoe N. F. | 12,060 | | | |
| Toiyabe N. F. | 10,184 | | | |
| Bur. of Reclamation | 64 | | | |
| | 107,826 | 107,826 | | |
| State: | | | | |
| California | 3,552 | | 3,552 | |
| Nevada | 6,047 | | 6,047 | |
| | 9,599 | | 9,599 | |
| Counties and Cities: | | | | |
| Alpine | 4,170 | 4,170 | 0 | 0 |
| El Dorado | 96,887 | 81,348 | 3,535 | 12,004 |
| Placer | 46,291 | 12,124 | 17 | 34,150 |
| Washoe | 19,700 | 2,731 | 3,020 | 13,949 |
| Douglas | 23,538 | 6,619 | 709 | 16,210 |
| Carson City | 5,830 | 834 | 2,318 | 2,678 |
| South Lake Tahoe City | 5,482 | 0 | 0 | 5,482 |
| Total land area | 201,898 | 107,826 | 9,599 | 84,473 |
| Lake Tahoe area[2] | 122,628 | | | |
| Small lakes area | 3,352 | | | |
| Total, Lake Tahoe Region Planning Area | 327,878 | | | |

1/ National Forest land except 64 acres in Placer County controlled by the Bureau of Reclamation.
2/ At legal elevation of 6,229.1 feet above mean sea level.

Nearly half (48.7 percent) of the land area is federally owned—chiefly in three National Forests totalling 107,762 acres. An additional 4.5 percent is state owned, nearly all in State Parks. Thus about 53 percent of the land in the planning area is publicly owned.

Of nearly 75 miles of lake shoreline, about 18 percent is publicly owned. This is chiefly 8 miles belonging to the State of California and 5.5 miles in National Forests.

**Tahoe Regional Planning Agency** (TRPA)

The Tahoe Regional Planning Agency began work as soon as the governors of California and Neveda signed the proclamation creating the Bi-State Planning Agency. Public Law 91-148 had enumerated the dangers of deterioration of the natural environment at Tahoe and of the increasing demands on various natural resources and features of the Region; also, it emphatically stated the need to maintain equilibrium between the Region's natural endowment and limitations on one hand and the environment that man is creating. It recognized need for establishing "an area-wide planning agency with powers to adopt and enforce a regional plan of resource conservation and orderly development, to exercise effective environmental controls, and to perform other essential functions. . . ."

TRPA was ordered to develop and adopt, within 18 months of its formation (i.e., by September 1971), a plan for regional development that would include separate plans for land use, transportation, conservation, recreational development, and public services and facilities, to name a few. The Agency was further directed to consider and to seek to harmonize the needs of the whole Region with the plans of local governmental units and the existing land use plans of State and Federal agencies.

Since nearly half of the land area in the Lake Tahoe Region is in National Forests, the Forest Service has major responsibility for improving environmental features here. In 1970 it established the Lake Tahoe Basin Planning Team to work with TRPA. Although the Agency and Team have separate organizations and responsibilities, they have cooperated closely to achieve a common goal.

# GEOLOGY FOR LAND USE PLANNING IN THE LAKE TAHOE BASIN[1/]

## INTRODUCTION

Application of geology to planning and development programs usually has been limited to use of such geologic specialties as engineering geology, mineral resources, and hydrogeology. Use of geologic information has been expanded recently for application in both regional and local planning, with particular emphasis on basic geologic studies for land use planning. Many data that geologists collect are readily adaptable as input to cope with or aid in solving many basic environmental problems related to man's incessant need to develop the land. The numerous data that geologists can make available to planning and developing groups for use in judicious planning of land use can be divided into five general categories:

1. Basic geologic mapping data for physical planning for structures on or under the land and the areal distribution of the various rock types.

2. Physical and engineering properties of rock materials as they relate to disturbing the land, difficulty in excavation, and stability of slopes and fills, and effects of siltation and sedimentation.

3. Assessment of availability and use of rock and mineral resources. Such data include present and projected needs as well as the necessity of protecting the known or potential reserves for future recovery and use.

4. Disposal and management of waste materials, both liquid (sewage) and solid matter. Investigation and evaluation of potential disposal areas are primarily the task of geologists, soil engineers, hydrogeologists, and sanitary engineers. The overwhelming increase in the amount and variety of waste materials and the scarcity of land usable for disposal sites inexorably dictate extensive subsurface testing and the monitoring of both surface and subsurface.

5. Information about development and management of water resources, which is vital because it relates to availability, water quality, and water use (mainly for consumption and recreation). Studies should include information about both surface and subsurface waters.

Four of these five broad categories of information are included in this study. The report *Comprehensive Study on Protection of Water Resources of Lake Tahoe Basin through Controlled Waste Disposal* (Engineering Science, Inc., 1963) states the importance of geology in land use planning in the Basin[2/] An environmental geologic study of the Lake Tahoe basin was completed in accord with this concept.

Within the scope of this study, a regional geologic map and report to supply information about distribution of the basic geologic or rock units was prepared (Plate 1, in map pocket). This map is most important to show the regional distribution of the surface geology. Data used to prepare this map enabled development of an interpretive table on engineering and physical properties of rock units (Appendix I). This table outlines the geologic units that have special characteristics that will be affected by or will affect development through land disturbance.

In the spring of 1967, the geologic study was undertaken as part of a program for collecting coordinated resource information conducted by three divisions within the California Department of Conservation. The purpose of these studies was to develop resource information to assist local government units in planning land use for the Lake Tahoe Region.

The California portion of the Tahoe basin was divided into northern and southern sections. Matthews studied the northern section (Placer County and parts of Nevada County) and Burnett the southern section (El Dorado and Alpine Counties). The political boundary fortuitously nearly coincided with a natural geologic boundary: the northern part of the basin is predominantly volcanic

1/ Study by Robert A. Matthews and John L. Burnett, geologists, California Division of Mines and Geology.
2/ See opening paragraph of Chapter 4, "Geology and Hydrogeology."

rock, while the southern part is mainly granitic. Field work was completed during the snow-free months of 1967, 1968, and 1969. Reconnaissance geologic mapping for the Nevada portion was compiled from various governmental studies and theses and modified by Matthews and Burnett. During this study technical advice, encouragement, and much help were given by government officials, land owners and developers, other interested individuals, and scientists too numerous to record individually; so this report is truly a group effort.

## SUMMARY AND CONCLUSIONS

Geological investigations in the Lake Tahoe Region were carried on during the month of June through October, 1967 through 1969. Preliminary reports and geologic maps were completed by Burnett (1967) and Matthews (1968) for the southern and northern parts of the basin, respectively. These reports were released through open file and made available to governmental planning groups, to private and public groups, and to individuals involved with studies in the Lake Tahoe basin.

These reports were utilized in conjunction with and in the preparation of the geologic section of this report. Concurrently with the geologic study numerous special study reports were prepared and were directed mainly towards problems of waste disposal and problems related to construction and development. Many data from these studies were used in preparing the land use and environmental section of this report. Geologic information related to erosion, sedimentation, and engineering and physical properties of earth materials was generated during this 3-year study.

This report synthesizes geological data into a form that we hope is meaningful and usable to the Tahoe Regional Planning Agency and the various local governmental planning and public works groups.

This study shows that the Lake Tahoe basin is essentially an open system and that the effect of natural and manmade changes will alter the environment. Interreactions resulting from these changes are not fully understood and should be carefully evaluated by individuals or groups with capabilities to handle the problem. Organization of ecological or environmental planning groups such as the U.S. Forest Service Planning Team will offer much of the expertise needed to advise and aid in regulating many of the innumerable problems in planning and development of the basin. It is imperative that such groups consist of persons having adequate experience in such subjects as soils engineering, engineering geology, landscape architecture, botany, biology, sanitary engineering, geography, climatology, forestry and economics.

## RECOMMENDATIONS

1. A detailed geologic and land use planning study of the Nevada part of the Lake Tahoe basin, supplementing this study of the California side of the basin, should be planned and completed as soon as is feasible.

2. Since the effects of natural and manmade changes have already altered the Tahoe environment, the inter-relations resulting from these changes (many are not yet fully understood) should be evaluated carefully by qualified individuals or groups.

3. Such ecological or environmental planning organizations as the U. S. Forest Service's Tahoe Basin Planning Team can provide much of the expertise needed in solving many problems in planning and developing the basin. Such groups should include persons with broad experience in such disciplines as soils engineering, engineering geology, botany, landscape architecture, biology, sanitary engineering, geography, climatology, forestry, and economics.

4. The technical staff of the Tahoe Regional Planning Agency should include an engineering geologist experienced in development of mountain terrain. Since major problems of pollution of the Lake Tahoe basin can be related directly or indirectly to geological conditions, it is imperative that competent advice and recommendations be available to planners.

5. City and county jurisdictions should also include on their staffs or in a consulting capacity a competent engineering geologist who has had experience in development in mountainous country. His principal duty would be to reveiew all proposals for development at both the initial and final stages.

6. Feasible effective methods of preventing and controlling of erosion and sedimentation adapted to this area should be developed. The ideal method would be to prohibit or severely restrict any development of the areas having the highest potential for erosion. Other less demanding and sometimes more practical methods are:

   a. Strongly limiting the amount of land disturbance in sensitive areas.

   b. Enforcing stringent requirements to control disturbance of natural drainage areas.

   c. Prohibiting construction in floodplains and meadows and prohibiting relocation of major stream channels and serious disturbance of these sensitive areas.

   d. Determining feasibility of constructing catchment basins for sediment in areas where sediment transport is heavy.

   e. Requiring detailed technical review by a competent engineering geologist (experienced in construction in mountainous areas) of all proposed development in the basin prior to issuance of any permit.

   f. Setting a limit on erosion and production of silt in the use permit and requiring a bond to provide for any needed corrective action.

   g. Requiring specific procedures for controlling erosion in development of areas of natural drainage (e.g., use of cobbles and boulders to line channels to retard flows of surface runoff).

## GEOGRAPHY AND GEOLOGIC FEATURES

### Geography

Area of the Lake Tahoe basin is slightly more than 500 square miles; 315 square miles is land, and the remaining 191 square miles is water surface. This alpine basin is in an eastward bulge of the Sierra Nevada; the Carson Range forms highlands to the east, and the true Sierran crest the highlands to the west. About two thirds of the basin is in the California Counties of Placer, El Dorado, and Alpine; Washoe, Carson City, and Douglas Counties in Nevada encompass the other third. The City of South Lake Tahoe and Carson City, which in 1970 extended its city limits into the Tahoe basin, are the only incorporated cities in the basin.

Elevation ranges from about 6,225 feet (mean level of the Lake) to 10,887 feet at Freel Peak in the southeastern part of the basin. Several peaks more than 9,000 feet high rise along the crest of the ranges that rim the basin. Maximum legal elevation of the Lake's surface is 6,229 feet; minimum legal elevation is 6,223 feet. A concrete dam built in 1865 controls release of Lake Tahoe water to the Truckee River, its only outlet, which drains into Pyramid Lake northeast of Reno.

With a maximum depth of about 1,645 feet, Tahoe is the third deepest lake in North America. Its volume is about 122 million acre feet (40 trillion gallons); it is fed by some sixty tributary streams. Annual precipitation, principally snow, ranges from about 15 inches in the central part of the lake to more than 45 inches along the western crest of the basin. Average temperature ranges from 26° to 30° F. in winter to 60° to 65° F. in summer.

Land areas that slope less than 25 percent are most likely to be considered for development. Such land comprises about 35 percent of the total area of the basin and is principally in El Dorado County. Main centers of current development are in Lake Valley in El Dorado County; but recent extensive development has been in the northshore area, and it is accelerating.

### Geologic Features

The southern part of the Tahoe basin is a flat plain of lakebed deposits, glacial outwash, and glacial moraines bounded by high peaks of granite and metamorphic rocks. The northern part is mantled by extensive volcanic rocks. The basin was formed by faulting, and the lake occupies a down-dropped block or graben that is bordered by steep faults. The box-like configuration is characteristic of other basins in Basin and Range structures to the east.

Major landforms within the Lake Tahoe basin and nearby areas were formed by faulting, warping, and combinations of both. Faults along the margins have not been delineated in detail. However, the physiographic expression of the steep, near vertical drop-off areas along the shoreline clearly suggest that steep faults bound the basin. Results of the U.S. Coast and Geodetic hydrologic survey of about 1906 and later air-gun profiles (1969) of the lake basin show steep faults along the margins of the lake.

The oldest rocks here are sedimentary and volcanic rocks that have been metamorphosed and are now preserved as remnants in granitic rocks. These older rocks are sporadically exposed in the eastern and western parts of the basin, mainly along the crest of the basin divide.

Granitic rocks underlie the entire basin; however, in the northern and northwestern parts the basement rocks are covered by younger Tertiary and Quaternary volcanic rocks. These are mainly mudflow breccias, basaltic flows, and minor masses of intrustive volcanic rocks and sedimentary rocks that were derived through the erosions of the volcanic and granitic rocks. Younger glacial moraines, tills, glacial outwash, and lakebed sediments form extensive deposits in the southern part of the basin; similar but less extensive deposits lie to the northwest but are much less common in the eastern part of the basin in Nevada.

## *GEOLOGIC UNITS*

A. **Metamorphic Rocks** (Map units: $mv_{1,2,\&3}$ ; $ms_{1,2,3,4,5,6,\&7}$ ; mv, ms, & m)

The oldest rocks in the Lake Tahoe area are sedimentary and volcanic rocks that have been altered in composition, texture, or internal structure by heat and pressure and by the effect of intense heat given off by granitic rocks that intruded them. Largest exposure of these rocks in this area are west of Fallen Leaf Lake in the Desolation Valley Wilderness Area and from the crest of Mt. Tallac and other major peaks that form the basin divide. Originally these rocks were deposited on the floors of ancient oceans and are similar in type and age to numerous other occurrences in the Sierra Nevada. Fossils indicate that the metamorphic rocks near Fallen Leaf Lake are about 150 to 200 million years old. The ancient sedimentary and volcanic rocks were originally deposited as nearly flat-lying beds and flows but have later been squeezed and bent into folds and broken by faults. The older sedimentary rocks are mainly marine deposited sand, silt, mud, and organic material. The volcanic rocks are mudflows, volcanic ash (tuffs), and bedded flows that overlie the sedimentary rocks and aggregate a thickness of more than 15,000 feet. These metamorphic rocks are mainly dark, dense, and hard, and they resist weathering processes; they appear as bold reddish brown to dark brown iron oxide stained exposures on rugged steep mountain peaks. Mt. Tallac is a good example. Weathering takes place mainly along closely spaced joints, foliation, or bedding planes; and blocky jumbly masses of talus form below the peaks. Talus slopes have developed in valleys that were not glaciated during the latest glacial stages, while those that were glaciated have landscapes with scattered rocky masses and thin rocky soils.

B. **Granitic Rocks** (Map Units: $gr^a$, $gr^g$, $gr_g$, $gr_d$, $gr_c$, gr , & di)

The principal rock unit that forms the basement or bedrock of the Lake Tahoe basin is granitic rock. The term "granitic" is used here to describe all intrusive rocks that range in composition from granite to gabbro. Granitic rocks are relatively common in the Sierra Nevada and other parts of California. The principal granitic rock in this area is granodiorite, which is the most extensive through the Sierra Nevada. No extensive occurrences of granitic rocks have been mapped in the northern part of the basin in California; however, these rocks underlie the younger volcanic rocks of this area and constitute more than 55 percent of the exposed rock in the remaining portions of the basin.

Although most people recognize granitic rock, a brief description of textures and other physical characteristics important to understanding how these rocks are affected by natural and man-induced changes is included here. A fresh unweathered surface of granite rocks is typically coarse grained; that is, the individual mineral grains are visible to the eye without magnification. These mineral grains are mainly light-colored feldspar and quartz, but they also contain darker (green and greenish black) biotite and hornblende minerals on an intermeshing mass of minerals; some show well formed crystal faces but others are poorly developed; some have no visible crystal form. Such granitic rock is tough, firm, and relatively durable. Deeply weathered granitic rock may appear to greatly resemble the fresh unweathered rock, but close observation or testing shows absence of the tough,

durable, cohesive character of the intermeshing mineral grains. Alteration, both chemical and/or physical, destroyed the bond between grains and the rock may readily crumple with little disturbance. Chemical alteration generally attacks the feldspar minerals of the granitic rocks and may alter these minerals to clay. This alteration results from the action of water charged with organic acids present in soils overlying the granitic rock. Physical alteration may supplement or accelerate chemical alteration. Much of this type of alteration is the result of water and cracks or fractures in the rock. Water seeps into the cracks and during the cold season freezes and disintegrates the rock by frost wedging (expansion in volume when water crystallized to ice). This effective mechanism, which is quite common in high alpine areas, causes a very unstable situation and is the source of numerous geologic hazards. (A section below on geologic hazards describes this problem in detail.) This distribution of granitic rocks is well illustrated by Plate 1. These rocks, as noted earlier, are very extensive in the southern and eastern parts of the basin. The hazards associated with alpine granitic terrains in the Tahoe basin are of two basic types: rockfalls on steep slopes of massive granite and erosion of decomposed granite on both gentle and steep slopes.

The instability of granitic rock has great significance in the Tahoe basin because granitic rocks constitute the major rock unit exposed here, and they underlie the steep slopes of the higher elevation areas.

### C. Volcanic Rocks

*Older Volcanic Rocks and Associated Sedimentary Rocks* (Map Units: $Tv^{o}$, $Tv^{p}$, $Tv^{p}_{r}$, Tv , $Mv^{r}$, Tf, and $Tc^{r}$).

Following erosion and uplift of the granitic rocks, volcanic rocks were erupted over large areas of the Sierra Nevada. In the Tahoe basin the older volcanic rocks consist mainly of lava flows, tuff breccias, mudflow breccias and minor volcanic ash. Although eruptions of these andesitic centers were widespread throughout most of the basin, the main volcanic centers were concentrated in the northwest.

Sources or vents for the eruption of these extensive lava flows and associated tuff and mudflow breccias have not been identified, but their areal distribution pattern indicates that they may have traveled long distances (tens to hundreds of miles) down relatively gradual slopes. Andesite lava flows, shallow intrusive masses of essentially the same composition as the flow rock, and flow breccias are more resistant to weathering and erosion. However, many of these older volcanic flows are broken and sheared along northwesterly trending faults or a conjugate system of faults, and these fractured rocks are more readily attacked by weathering and erosion. Other areas where the andesite flows are porphyritic and coarse grained, the weathering characteristics are more similar to granitic rocks.

Much like the granitic rocks in the southern part of the basin, the volcanic rocks are most important geologically in terms of their widespread distribution, weathering characteristics and in many instances the high susceptibility to erosion, i.e., poorly indurated mudflow breccias and tuff breccias. Most landslide areas (Plate 1) are in the poorly indurated units. In the northern part of the basin, the main rock units are volcanic, and the problems of weathering and decomposition are not widespread. The weakly indurated mudflow and tuff breccias tend to weather and decompose very much as granitic rocks do and produce similar erosion problems; however elevation and degree of slope here are not as severe as in the southern part of the basin. These younger volcanic rocks have been exposed to the elements for a much shorter time (geologic) than the older granitic rocks. The texture and mineral composition are such that many characteristics of granitic rocks that promote weathering are not found in the volcanic flow rocks. Such physical properties control the erodibility of the rocks; however the problem of erosion in rocks of the northern part of the basin is not one of rock type but of type and thickness of soils derived from these volcanic rocks. The soils are generally shallow (in the order of a few feet to tens of feet) and consist of fine grained (silt to clay size) material rich in iron and magnesium but low in silica. These soils support adequate vegetation (grasses, shrubs, and conifers—mainly Jeffrey pine, white fir, and red fir—at higher elevations) and under a cover of natural forest litter they resist erosion. Erosion as a result of construction or similar activities that remove the protective vegetative cover generally progresses at a rapid and excessive rate.

Since the eroded material is silty, it is readily transported by streams, sheet flow, and other means to the Lake. Evidence of such silt masses reaching the Lake has been documented by aerial views of streams draining areas of fine grained silty soils (Goldman, 1967, p. 10).

Sedimentary rocks overlying the older tertiary volcanic rocks have been classified as the Truckee Formation; however, the rock types (composition), texture, and local areas of deposition are so diverse that a formational name is meaningless. However, along the north coast of Lake Tahoe these sediments are mainly lakebed and stream deposits. The bulk of material making up these deposits is debris from the older tertiary andesitic volcanic rocks, diatomaceous-rich shales and fine grained volcanic ash, silt and clay. Deposits of pebbles, cobbles and boulders with coarse bedded sand lenses interlayered with fine grained, well bedded silts, shale, diatomite and diatomaceous shales illustrate both lacustrine (lakebed) and fluviatile (stream deposited) deposits, some of which have been faulted and tilted up to 20 degrees and indicate that both tilting and faulting were factors in forming the lake basin. Diatoms from the lakebed parts of these sedimentary rocks indicate that they are late Pliocene or younger in age. (Cleveland per communication)

Other discontinuous and isolated basin deposits of lakebed and streambed sediments that occur throughout the basin and that either overlie granitic rocks or the older tertiary volcanic rocks are probably contemporaneous with those found along the north Tahoe basin.

*Younger Volcanic Rocks and Associated Sedimentary Rocks* (Map Units: $Qv^{1}$, $Qpv^{b}_{1\&2}$, $Qpv^{c}$; $Qpv^{1}_{1,2,3,\&4}$, $Qpv^{r}$, Qpv, $Qpv^{1}_{a,b,c,\&d}$, $Qpv^{b}_{b}$, $Qpv_{e}$, Qlt and $Qlt_{1,2,3,\&4}$).

Overlying the "Truckee" type sedimentary rocks are basalt and latite (?) flow rocks. These rocks cover large areas northwest and northeast of the basin, the Truckee River basin northwest of Lake Tahoe and along the western and northern shores of the Lake. Several volcanic center source areas for the flows are characterized by cinder cones. Associated with these separate flows of basalt and latite (?) are intrusive volcanic masses of essentially the same composition. Several of these volcanic necks or plugs are exposed as massive resistant monoliths that form distinctive landmarks along the west, north, and east shores.

Well developed conjugate joint fractures characterize the flow rocks and intrusive volcanic rocks and result in development of extensive talus slope below steep-sided outcroppings. These younger volcanics are extremely resistant to weathering and generally only very thin soils develop.

Steep dipping normal faults cut these younger volcanic rocks and in places along the north shore they have been tilted. These faults evidence the seismic activity of the area and also indicate another potential geologic hazard of seismic shaking from earthquake forces. The September 1966 Truckee-Boca earthquake of magnitude 5.8 and a less severe (4.3 magnitude) earthquake in April 1971 centered in the same general area point out this potential geologic hazard. Minor intervolcanic sediments, mainly gravels, are associated with the flows. Cinders and scoriaceous flows are commonly restricted in areal extent to a few hundred feet of the eroded vent areas.

D. **Glacial Deposits** (Map Units: $Qm^{1,2,3,4,5}$, Qm, $Qg^{3,4,5}$, and Qg)

Several stages of glacial activity strongly modified terrain in the Lake Tahoe basin. Glacial advances were followed by periods of melting and retreating of the glaciers that generated extensive glacial moraines and melt water runoff. The erosive activity of this runoff further modified the landscape.

The main canyons draining the mountain peaks above 9,000 feet that form the basin divide are mantled by extensive glacial deposits. Many deposits of glacial moraines occur in canyons draining into the upper Truckee River, other sub-basin areas, the Truckee River downstream from the outlet of Lake Tahoe, and the main stream canyons draining into the Lake. Most of the area underlying the City of South Lake Tahoe is of glacial origin.

Several types of glacial deposits have been delineated on the geologic map. These include *glacial till*, which is unsorted, unstratified rock material that was deposited from the undersides of a glacier and which generally makes up the floor of the glaciated valley; *moraines*, which are mounds of unsorted and unstratified rock materials that were formed by bulldozing action of the moving glaciers. These mounds are called *terminal moraines* when deposited at the terminus of the glacier, and *lateral moraines* when formed along the flanks. *Glacial outwash* deposits are composed of sorted and stratified glacial materials that have been transported by water flowing from the glacier.

Of the five separate glacial events in the Lake Tahoe basin only the three older events (pre-Tahoe, Tahoe, and Tioga) are significant in land use planning studies. The map symbol Qm (Plate 1) designates undifferentiated glacial moraines, and the symbols $Qm^{1}$ through $Qm^{5}$ indicate moraines of increasing age.

The two youngest glacial events ($Qm^1$ and $Qm^2$) have no particular significance since they occur primarily in cirques in high peak areas and are of restricted size and distribution. The oldest deposits, designated $Qm^5$ (pre-Tahoe materials), are also the most extensive in both northern and southern parts of the basin. In the north and south the true extent of the older deposits is in part obscured or removed by the later glacial events.

*Older Moraines* (Map Unit $Qm^5$)

The oldest moraines are characterized by deeply weathered boulders of granitic rock and, to a much lesser degree, weathered coarse-grained volcanic rocks. The degree of weathering and development of clay minerals depend upon location and type of source materials constituting the moraines. The pre-Tahoe moraines that developed in the southern part of the basin are characteristically composed of thoroughly weathered (punky) granitic rocks in decomposed granitic sand to clayey matrix material. In the northern area the boulders are mainly weathered volcanic materials with a minor quantity of deeply weathered granitic boulders in sandy decomposed granitic material and more abundant silty and clayey material. In the northern area the boulders are mainly weathered volcanic materials with a minor quantity of deeply weathered granitic boulders in sandy decomposed granitic material and more abundant silty and clayey material.

These older moraines also differ in the development of soil profiles. The soil profile is poorly developed in the predominantly sandy granitic moraines in the southern part of the basin while shallow but better developed soils are present in the northern volcanic areas. These older moraines have been modified by erosion and only the largest ones retain much of their original shape. The best examples are the long ridges east of the Tahoe Valley airport. These glacial deposits throughout the basin are characteristically well compacted; however, construction or development of areas underlain by these deposits presents rather severe problems. The naturally compacted and stabilized nature of the material when disturbed offers little resistance to erosive action during runoff or disturbance during construction activities. Rigid grading controls should be adhered to in development of these areas.

*Tahoe and Tioga Moraines* (Map Units $Qm^4$ and $Qm^3$)

The Tahoe and Tioga Age Moraines have many similar physical and engineering characteristics and for purposes of this report are discussed together. Although many granitic boulders and cobbles in the southern area are more deeply weathered in the older (Tahoe) of these two glacial units, the difference is much less distinct in other areas where the percentage of granitic material is much less. Both these glacial units have better developed morainal form, and the younger (Tioga) is characterized by sharp crests and relative abundance of unweathered boulders and cobbles. The abundance of sound boulders and cobbles helps these moraines to resist erosion and to supply a source of cobbles and gravels to further protect stream beds draining these areas. Both Tahoe and Tioga glacial materials occur in areas that are prime building sites presently being developed and areas of probable future development. If good engineering practices are adhered to, stability problems should be minimal.

*Glacial Outwash Deposits* (Map Units $Qg^{3, 4, \& 5}$; Qg)

Most areas within the drainages of major streams of the basin and principally areas topographically lower than the moraines contain thick widespread deposits of unconsolidated silt, sand, pebbles, cobbles and boulders of rock material eroded from glacially deposited materials by stream action. Much of the low relief area in South Lake Tahoe is underlain by the reworked glacial material and has been deposited in well bedded layers of granitic material—boulders, cobbles, gravel, sand and silt. In the northern area the deposits are not as well bedded and consist of similarly graded material of volcanic rock types and more abundant silt and clay material and less sand. In the very low relief areas in the northern part of the basin, a thin zone of soil over-lies outwash deposits and protects them from excessive erosion. When this soil cover is removed by development activities, the remaining soil and outwash materials are readily eroded. Those outwash deposits further upslope are considerably coarser, contain less of the finer silt and clay-size particles, and are more resistant to erosion. Those outwash deposits located within the high water floodplain of the major streams tend to have steep slopes, and disturbance during construction generates erosion and siltation problems. In general, sound engineering practices should be stressed in these erosion-prone areas. Most of the rock construction material is recovered from the glacial outwash deposits, and the outwash deposits merge almost imperceptibly into lakebed deposits.

E. **Lakebeds and River Alluvium** (Map units Rl, Ql, Qal)

Most of these deposits are of glacial origin in the sense that most of the rock material in them has been removed from its original outcropping by glacial ice; but they have also been carried by running water and laid down by the action of streams and rivers. Stream-laid deposits can be identified by the bedding seen in cross-section. Each individual bed is made up of a size range that depends upon the speed at which the water was moving — large particles were deposited from swiftly moving water while small grains of silt and clay could have settled only in the still water of a lake. Many coarse sand deposits contain irregular beds that abruptly thicken or thin, indicating periods of torrential flooding when glacial ice was melting most rapidly.

Glacial outwash and older lakebed deposits were laid down during and after the main advances of the glacial ice, and the older deposits were buried by material from the younger glacial stages. Rivers that transported this material deposited the large-sized particles close to the lower end of the glaciers and carried the fine sand and silt far out, toward and into Lake Tahoe. Many isolated small exposures of lakebeds and outwash appear throughout the basin up to an elevation of 6,800 feet. These deposits must have been laid down during periods when the level of Lake Tahoe was as much as 500 feet higher than it is today. Birkeland (Wahrhaftig, Morrison and Birkeland, 1955) recognized that the Lake had risen at least 90 feet during Tahoe times and suggested that pre-Tahoe glaciation accounted for a rise as high as 600 feet.

The three types of material within this group have characteristic features that permit reasonably certain identification. Glacial outwash contains cobble- and sand-sized particles and is well bedded although the beds may be uneven and cross-bedded. The lakebed deposits contain silt and clay-sized particles and have very even beds 1/2 to 2 inches thick. Both glacial outwash and the lakebeds are well compacted. River alluvium contains loose pieces of clay, silt, sand, and cobbles that are being moved along present river channels by stream action.

*Older Lakebed Deposits* (Map Unit Ql)

Older lakebed deposits of silt, sand, and clay are more widespread and extensive in occurrence than the younger lakebed deposits and differ from them in several ways: They are more highly compacted; overall thickness is greater; and are generally covered by thicker soil. Some of these older lakebed deposits have been structurally deformed presumably by tilting, faulting, or slumping. These deposits were formed during several periods when the Lake's surface was higher than it is now. Deposits of this type were noted at elevations up to 6,800 feet, i.e., some 750 feet above the present level of the Lake. The younger lakebed deposits are less extensive but are more widely distributed and are formed as the result of sedimentation of relatively shallow lakes that occupy low areas or that were dammed by older glacial deposits.

Although these older lakebed deposits are more highly compacted than the younger deposits, the engineering problems involved in construction and development are similar. These sediments under wet conditions have relatively low bearing strength and the resistance of these sediments to seismic shaking may be low, especially where they are underlain by silty or clayey layers. Diatomaceous rich zones which may pose construction problems are characteristic of many of these older lakebed deposits along the western and northern shores. In many areas much of the once widespread lakebed sediments have been stripped away by erosion; however where lakebed sediments have been protected by soil and vegetation but exposed by construction or other means, the degree and type of erosion can be observed. During heavy runoff, streams draining these areas derive much of their silt load from these poorly consolidated sediments.

*Younger Lakebed Deposits* (Map Unit Rl)

Deposits of similar fine grained materials that are mainly restricted to intermittent lakes or marshes constitute much of the younger lakebed sediments. Some of these areas are contemporaneous with the deposition and sedimentation now occurring in low land areas along the margin of the Lake where streams drain into it. They are distinguished from the older lakebed sediments by their lesser degree of compaction, association with very immature and shallow soils, and cobble, boulder, and gravelly sand deposits that represent depositions by torrential stream flow. Considerable areas in both the northern and southern parts of the Lake Tahoe basin are underlain by these unconsolidated deposits. These deposits of younger lake sediments are of relatively minor importance as potential building sites because they are located in unattractive lowland marshy areas and are scattered. The

sediments have very low strength especially when wet, and like the older lakebed sediments, are a poor risk in such a potentially seismically active area as Lake Tahoe. In addition, caution should be exercised in developing these areas since these low topographic areas act as catchment basins for sediment-laden streams that drain the higher areas. As Burnett suggested (1967), these areas might be stabilized and made more usable as catchment basins by constructing small dams or spillways; nevertheless any development of these lakebed or floodplain areas should be carefully planned to prevent ecological and environmental degradation as indicated in the goals and policies of the Tahoe Regional Planning Agency.

F. **Rockslides and Talus** (Map Units Qls and Qta)

Some of the youngest geologic deposits in the basin result from rock moving under the force of gravity from the high peaks and canyon walls into the valleys. Most often this movement is slow and results from rockfalls in which several or many blocks fail each season, usually during the spring thaw, building a talus deposit of blocky rubble. Occasionally a large mass of the hillside breaks away and sweeps downslope as more or less coherent rockslide.

## *GEOLOGIC HAZARDS*

Associated with the physical and engineering properties of earth materials in the Lake Tahoe basin is the problem of geologic hazards. Rocks that are loosely consolidated, highly fractured, or jointed underlie steep slopes and constitute landslide, talus, or rockslide areas; all may be, in varying degrees, affected by earthquakes. The Lake Tahoe basin is a seismically active area that demands consideration for this phenomenon in land use planning. (See Appendix II, Earthquake Hazards.)

### Seismic Considerations

No earthquakes with a Richter magnitude greater than 6 have been recorded in the vicinity of Lake Tahoe basin. However, if earthquakes of magnitudes comparable to that of the 1906 earthquake in San Francisco or the Alaskan earthquake of 1964 should occur, very extensive damage and loss of life would result because of some of the extensive land development in this area. Damage to structures might be minor in comparison to damage that might come from earthquake shock or large-scale landslide or massive slumping of sediments that might generate waves in the lake. Under such massive destructive action, damage to and possible destruction of the over-60-year-old dam at the outlet of the lake is within reason. Untold damage downstream to both persons and property would occur, and damage to the lake basin environment would be insurmountable. Such action is not predictable and may never occur; however, the possibility for it exists.[3/]

Lake Tahoe occupies a graben (down-dropped block) structure with very steep walls along much of its periphery. Fathometer surveys[4/] indicate large areas of slumped sediments and very steep, nearly vertical shorelines. A sparker survey study by Norman J. Hyne of the University of Southern California more precisely delineated these massive slump areas and zones of faulting. Many areas of steep-sided very poorly consolidated glacial and fine-grained volcanic sedimentary materials would be affected by large-scale (magnitude) earthquakes. Apparently some of these subaqueous deposits have been disturbed or triggered by prehistoric earthquakes since recession of the glaciers. Very jumbled areas of glacially derived sediments were involved in slumped areas.

### Faulting

Faulting that formed the lake basin is related to Basin and Range structures that extend from the Sierra eastward through Nevada and Utah to the Wasatch Range. The basin floor is about 2,700 feet above sea level. Preliminary sparker surveys by Hyne indicated that about 2,200 feet of sediment overlie the bedrock, which is principally granitic.

The outlet of the Lake is in the older Tertiary volcanic rocks. No granitic rock is exposed here, but it probably underlies the andesitic flow rocks and may have been upfaulted. Evidence for fault origin of the Lake is based upon existence of steep scarps bounding the lake basin on all sides, especially

3/ During preparation of this report, J. V. Fever, geologist in the U. S. Bureau of Reclamation, indicated that the Bureau is now studying effects of wave action on the dam at Lake Tahoe.

4/ Made by J. Court and others under direction of Dr. Charles Goldman, Institute of Ecology, University of California, Davis.

along the western and eastern margins. Some tilting or warping was involved in formation of the basin, as can be seen in lakebed and volcanic flows along the north shore that have been tilted as much as 25 degrees.

In his study of the Truckee River north of Lake Tahoe, Birkeland (1962) mapped numerous faults that cut the younger volcanic rocks, some of which have been dated at less than 1.7 million years. Other faults that cut volcanic rocks dated at about 1.9 million years have been mapped on the north shore near Dollar Point. At Stateline Point a fault has been inferred along a line of springs near the contact between older Tertiary andesite flows and granitic rock, and a fault probably forms the steep scarp along the eastern boundary of Stateline Point.

Offshore topography indicates numerous faults east and south of Stateline Point, east of Dollar Point, and off Rubicon Point on the west shore. Norman Hyne's preliminary report on a sparker survey of the basin indicated that these scarp-like zones extend into the Lake for considerable distances, and it somewhat confirms the steepness of the near off-shore scarps around the Lake margin. Hyne's study also indicated that slump structures in the lake sediments occur in glacial outwash and in moraines; also that some of the most recent sediments appear to be cut by faults, one of which formed a steep scarp more than 20 feet high. This fault is in the central part of the lake basin south of Stateline Point and might be a continuation of a fault mapped on shore east of Stateline.

The 1966 earthquake that centered near Boca Reservoir formed a line of ground rupture that might indicate a zone of active faulting just outside the basin; certainly it suggests that faulting and possibly very recent or active faulting does occur in the basin (See Appendix II, which covers this point in detail).

## *FACTORS AFFECTING SLOPE STABILITY*

### Physical and Engineering Properties of Earth Materials

The differences in physical and engineering properties of the various rock types in the Lake Tahoe basin profoundly affect slope stability and, in turn, construction and development practices. In a general sense, the physical and engineering properties of earth materials in the basin are related to the geologic origin and weathering history of the rocks. For example, some of the young volcanic rocks in the northern part of the basin are not only young geologically, but they have greater strength and more resistance to physical decomposition than granitic rocks. These volcanic rocks generally form stable highlands that are difficult to excavate for development. However, talus slopes that form below steep-sided exposures of these rocks are very unstable. Because the talus deposits are on slopes that may be the maximum slope angle upon which rock remains at rest, any disturbance may cause rock material to fall. Slope angle is an important factor for all deposits of loose rocks because steep slopes are more likely to be unstable than gentle ones. (Physical and engineering properties of rock units in Lake Tahoe basin are summarized in Appendix I.)

### Weathering History of Rock Units

The weathering history and degree of fracturing have important bearing on the engineering and physical properties of rocks in the Lake Tahoe basin. Chemical and physical deterioration of rocks can be related directly to landslides, rock falls, and excessive soil erosion. Several factors are involved in the physical and chemical changes that affect weathering processes. Physical fracturing of rocks can be related to the effects of faulting, frost-wedging and glacial action, development of joints and such other minor causes as rock spalling resulting from forest fires.

The degree of weathering of rocks in the Lake Tahoe basin varies widely. The mode of origin and the effect of glacial scouring are important factors in this wide variation. Granitic rocks and coarse grained andesitic volcanic flow rocks develop the most extreme weathering, and the Quaternary volcanic flow and intrusive rocks are least affected.

Granitic rock constitutes approximately 55 percent of rocks exposed in the Lake Tahoe basin. Approximately 35 percent of these rocks are deeply weathered; examples can be observed in numerous cut slopes along U. S. Highway 50 in California and Nevada as well as in subdivision and ski development areas. Effects of erosion and sedimentation also are apparent in these areas.

### Steepness of Slope

The degree or steepness of slope is highly important in slope stability because steepness is one factor of runoff from snowmelt and rain. Steep slopes generate higher velocity in runoff and capability for erosion than shallow slopes. The type and degree of development of soil and the type, distribution, and density of vegetation are factors controlling erosion in this steep-wall internal basin structure. The surface litter formed from vegetation and decomposed rock material plays a very important role in the erosion cycle, and disturbance of this natural material by development practice invariably increases rates of erosion. Erosion is progressive in that succeeding runoff, unless controlled, enlarges channels in both horizontal and vertical directions. Geologic rock units underlying steep slopes have varied erosion rates that are related to rock type.

The degree of soil development, type and distribution of vegetative matter and forest litter, and such deterrents to runoff as the amount and distribution of surface boulders, broken or fractured rock—all affect the erosion potential of all units.

The risk of land instability is emphasized by seismic risk hazard of the Lake Tahoe basin. This problem is discussed in detail in Appendix II, but consideration of steep slopes points out the variance of degree of hazard of the geologic units (or, in more general and broader terms, the physical and engineer units). The effect of seismic shaking may be extremely serious on slopes greater than 25 percent. Again, the risk increases when these steeper slopes are subjected to treatments usual in land development.

### Rock Conditions

Several different geological processes have taken place in the Lake Tahoe basin, and each of these has had effect on the rock condition. Such processes as metamorphism, volcanic eruptions, emplacement of plutonic masses (granite), sedimentation and compaction or lithification of sediments, weathering of surficial rocks, scouring by glaciers, uplifting and down-dropping along faults, and downcutting by streams—all have affected the rocks in the basin. These processes resulted in fracture and crush zones, compaction and induration, foliation or cleavage (parallel or crudely parallel zones of layered or platy rock), large masses of hard rock in a matrix of finer grained unconsolidated material (glacial moraines), zones of alteration by hot, chemically laden waters, masses of blocky, rocky slopes resulting from freezing and thawing of rock surfaces (talus slopes), and masses of unsorted material that has moved downslope as landslides or mudslides. These conditions are important in determining the physical and engineering properties of the rock units and their resulting behavior towards erosion and land instability. Land instability features, which include erosion—both the stream gullying and mass wasting processes—are basically controlled by rock conditions. Such conditions as degree of shearing, fracturing, jointing (tension cracks), weathering, induration, presence of clay zones or zones of saturation and soil development under varying conditions contribute to problems of land instability. For example, highly jointed rocks, such as the metamorphic rocks in some steep-wall canyons develop thick, loose, blocky talus slopes, many of which are balanced precariously at about the angle of repose. Any development on or below these areas may result in rockfalls. Rock units cut by faults or occurring in fault zones may be sufficiently sheared that natural erosion and man-induced erosion may readily be affected during unseasonably high precipitation. Such rocks, like the unconsolidated lakebed and glacial sediments, are readily disturbed even on very shallow slopes by streamflow and runoff from snowmelt and rain.

Other rock units that vary in induration or degree of cohesion (e.g., the lakebed, glacial deposits, and alluvium) also vary in resistance to erosion. These weakly consolidated to unconsolidated sediments are highly affected by construction practices, and unless great care and well planned preventive measures are undertaken, excessive erosion or land instability problems will result.

### Landslides, Rockfalls, and Other Catastrophic Events

Landslides, rockfall, and similar problems of land stability are certain to occur in such an area as the Tahoe basin, which has high relief, rock masses with low stability, potential seismic activity, and expanding land development and construction. Very small to very extensive volumes of rock, soil, and mud have moved downslope, mainly in canyons, to alter the landscape. The rockslide at the head of Emerald Bay along Highway 89 is best known and is discussed later. Numerous other slides have occurred in all rock types; this rather forcefully illustrates one of the principal geologic hazards in the Tahoe basin. (For a classification of slides, see fig. 1.) Examples of the various types of landslide movement are illustrated in figures 2A through 2C.

A very large composite slide mass (about 125 million cu. yds.) about 1 mile northeast of the basin divide in Nevada moved downslope from an elevation of 9,400 feet to about 5,000 feet in 1852. This huge land mass is not within the immediate boundary of the Tahoe basin but is related in rock type and structure to Tahoe basin rocks and illustrates the kind, magnitude, and susceptibility of these rocks to catastrophic landslide movement. When such rocks that are oversteepened are tectonically fractured, and have joint patterns roughly parallel to the natural slope, are altered by unseasonally heavy precipitation and are further affected by intense earthquake shocks, massive slides may occur.

Lake Tahoe basin is not naturally highly susceptible to landslides or other problems of land instability; however, several slide areas have been triggered by construction practices, unseasonally high precipitation, and seismic shaking. In the southern part of the basin on the south slope of Monument Peak is an old landslide of size comparable to the Emerald Bay slide. Such a slide, even though considered inactive, does indicate a history of land instability. Numerous slides in different rock types, and in varying degrees of slope and size, occur along the Truckee River just outside of the basin drainage divide; another occurs in rocks just below the divide in Ward Creek sub-basin. Some rather well developed zones of exfoliation have formed in the rocks in these areas where fractures or joints separated roughly parallel to the topographic surface; such features are also dramatically illustrated in the Yosemite area.

| TYPE OF MOVEMENT | TYPE OF MATERIAL | | | |
|---|---|---|---|---|
| | BEDROCK | | SOILS | |
| FALLS | ROCKFALL | | SOILFALL | |
| SLIDES — FEW UNITS | ROTATIONAL: SLUMP | PLANAR: BLOCK SLIDE | PLANAR: BLOCK GLIDE | ROTATIONAL: BLOCK SLUMP |
| SLIDES — MANY UNITS | | ROCKSLIDE | DEBRIS SLIDE | FAILURE BY LATERAL SPREADING |
| FLOWS | ALL UNCONSOLIDATED: ROCK FRAGMENTS | SAND OR SILT | MIXED | MOSTLY PLASTIC |
| FLOWS — DRY | ROCK FRAGMENT FLOW | SAND RUN | LOESS FLOW | |
| FLOWS — WET | | | RAPID EARTHFLOW; DEBRIS AVALANCHE; SLOW EARTHFLOW | |
| FLOWS — WET | | SAND OR SILT FLOW | DEBRIS FLOW | MUDFLOW |
| COMPLEX | COMBINATIONS OF MATERIALS OR TYPE OF MOVEMENT | | | |

**Figure 1.—Classification of landslides (From Varnes, 1958).**

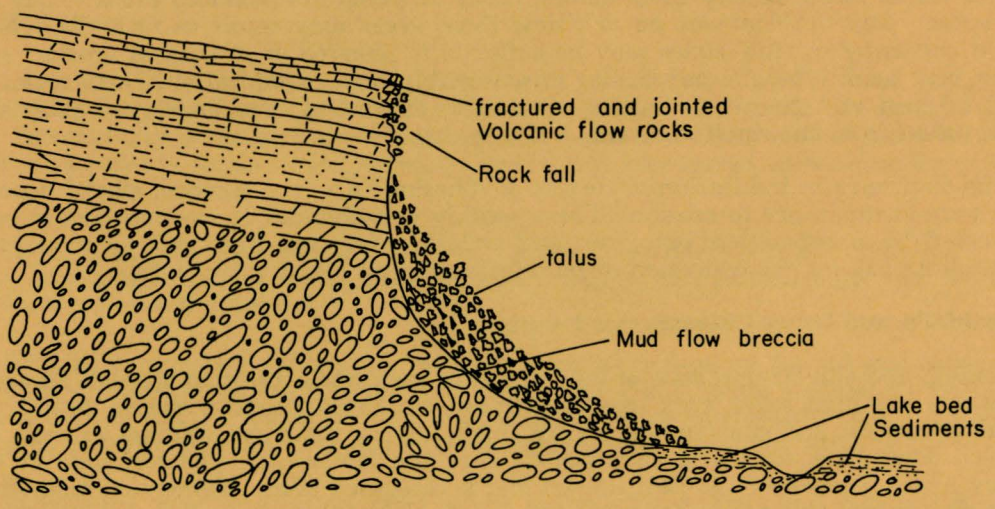


**Figure 2A.—Simple rockfall with well developed talus slopes, a common occurrence below oversteepened slopes in glaciated valleys in the Lake Tahoe area.**

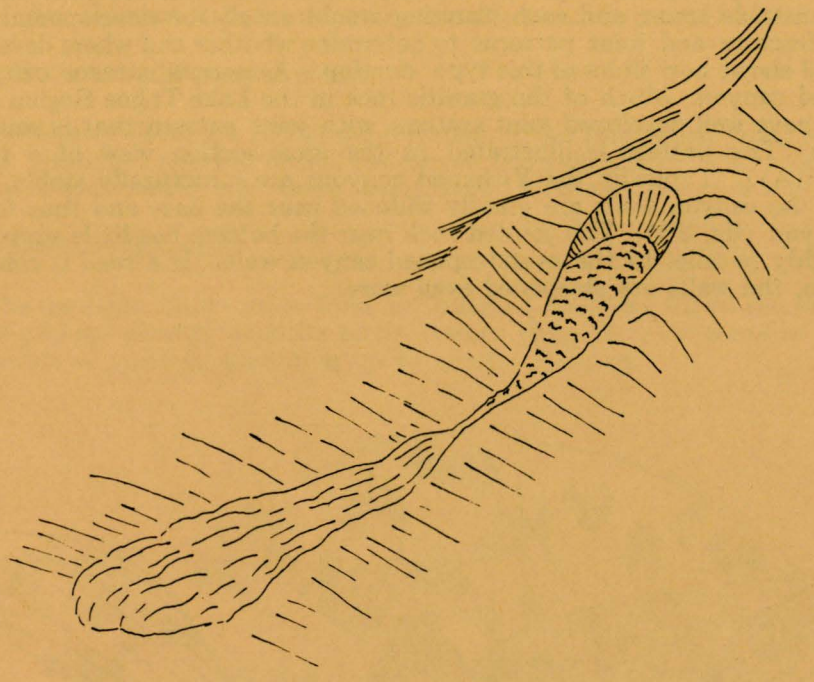

**Figure 2B.—Mudflow similar to the 1967 2nd Creek mudflow in the Incline Village area.**

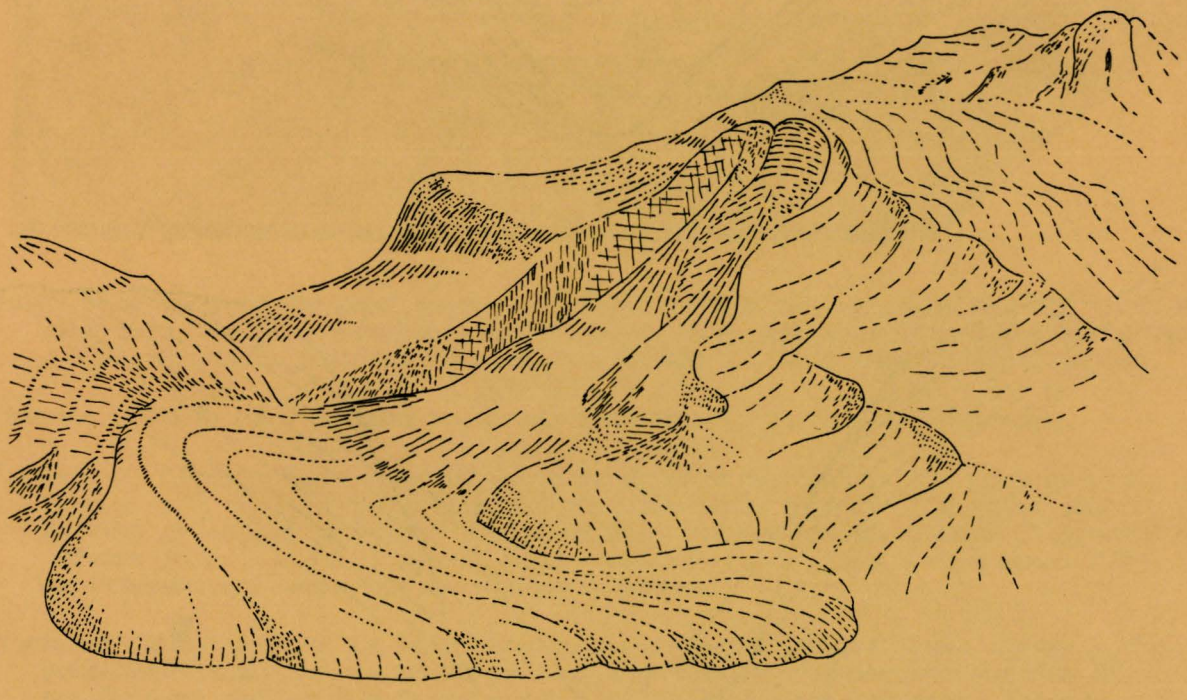

**Figure 2C.—Rockfall-avalanche similar to Slide Mountain slide north of Lake Tahoe near Mt Rose.**

Exfoliation shells or plates are underlain by steep slopes; however, if such slopes are disturbed, serious problems of slope instability may develop. Road and construction site development must be planned to avoid potentially unstable areas; and such planning would entail the development of engineering geologic data of the fracture and joint patterns to determine whether and where development should be permitted. Figure 3 shows how slides of this type develop. A normal stream canyon in granitic rock forms a V-shaped canyon. Much of the granitic rock in the Lake Tahoe Region and other areas of the Sierra Nevada have well developed joint systems with joint pattern that is roughly parallel to the topographic slope. This pattern is illustrated in the cross-section view of a typical V-shape stream canyon (fig. 3(A)). Typically the V-shaped canyons are structurally stable, but if they are modified by glaciers, the canyon walls are greatly widened near the base and thus form the characteristic U-shaped canyon (fig. 3B). The jointed rock near the bottom has little support, and exfoliation joints from roughly parallel to the oversteepened canyon walls. If a road is constructed on the face of such a canyon, the walls are steepened even more.

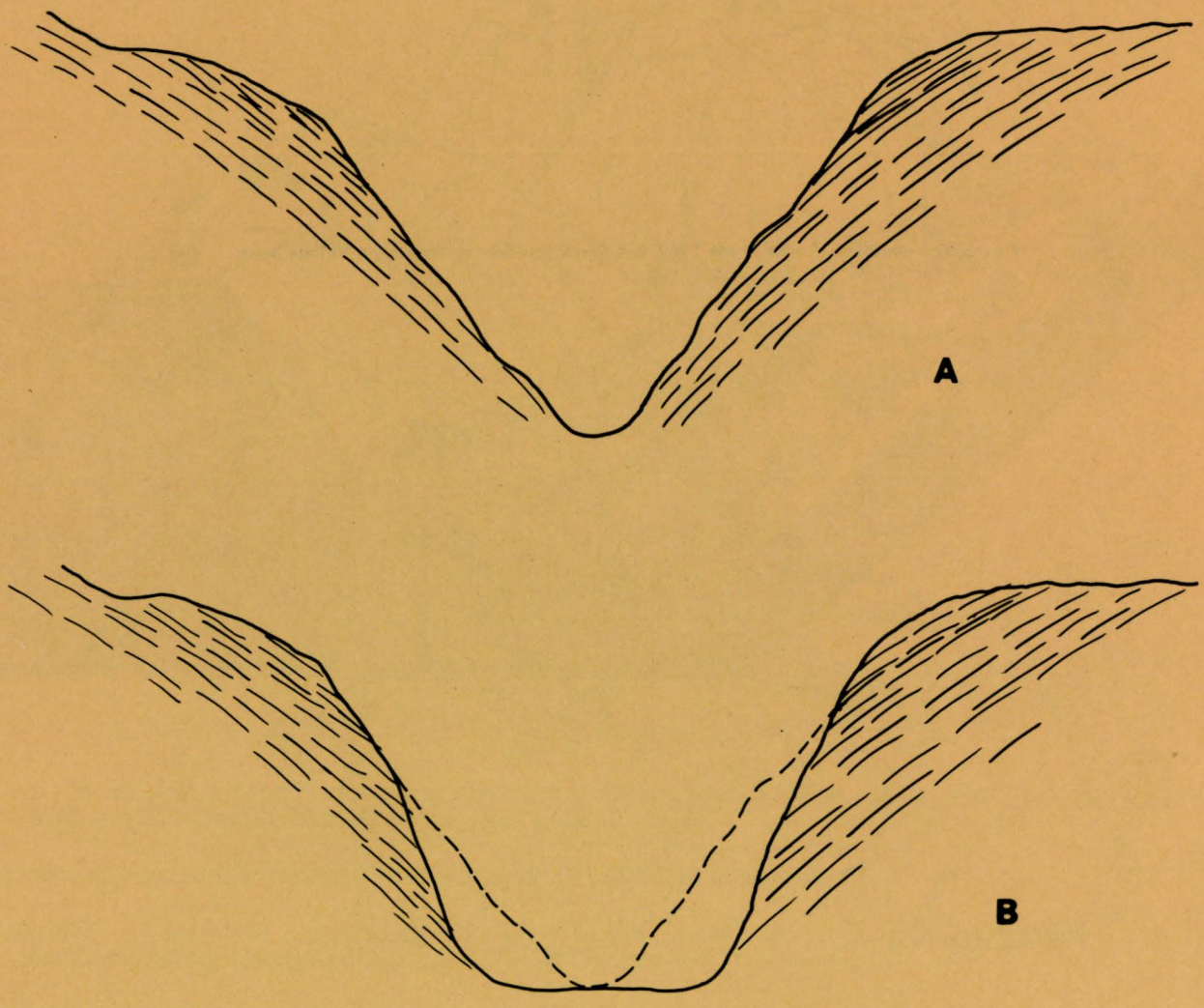


**Figure 3.—(A) Typical streamcut channel in jointed granitic rock.**

**(B) Subsequent modification by glacial scouring.**

Figure 4 shows how slides like the one at Emerald Bay develop. Walls of canyons that have been carved by glaciers often cover oversteepened slopes (fig. 4A). This slope with exfoliation and joint fractures roughly parallel to and steeper than the topographic slope, when disturbed by road construction (fig. 4B) creates an unstable condition which results in further steepening of slopes and recurring landslides and rockfall-avalanche type of landslides (figs. 4C and 4D).

Landslides of this type might occur in other areas of glaciated granitic rock having steep exfoliation and other joint fractures. Such problems of land instability are of greater than usual concern in this potentially seismically active area. Highway and roadway routes should be planned to avoid these potentially unstable slopes. Such plans would require preparing detailed geologic maps of the proposed route areas.

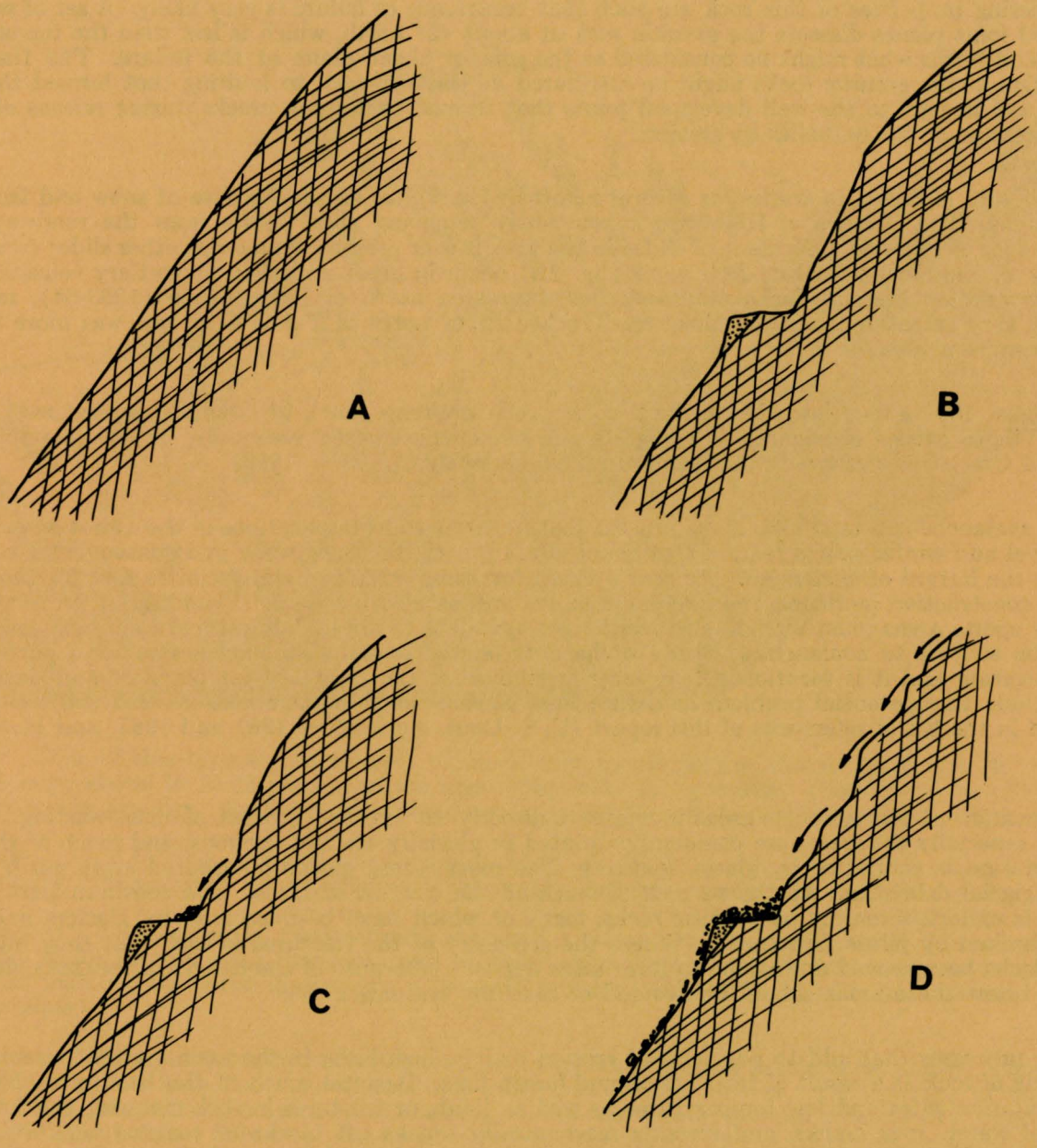


Figure 4.—Development of rockfall-avalanche slide on glaciated and jointed rock slopes.

The Slide Mountain slide mass, according to Piute Indian legend, occurred in 1852 following a high intensity seismic shock (Slemmons *et al.*, 1965). The degree of weathering, dissection, and alluvial cover indicate an older age for the slide mass, or at least the first stage of sliding (Thompson and White, 1964) (see fig. 2C).

Within the Tahoe basin, the large rockslide-avalanche mass at the head of Emerald Bay is undoubtedly the best known and most photographed slide in the area. This slide mass is traversed by State Highway 89 along the west side of Lake Tahoe. Construction on this roadway probably precipitated the initial movement of rock in this slide prior to the heavy precipitation season in 1953 when the area failed (Calif. Div. of Highways, 1957). Later, in the winter of 1955-56, following very extreme precipitation, a much more extensive failure nearly oblitereated the highway and moved downslope into Emerald Bay some 450 feet lower. Approximately 200,000 cubic yards was removed from the area above and on the roadway. The saturated rock mass probably moved suddenly as a rock-debris avalanche and possibly may have been triggered by a snow avalanche from above. The physical and engineering properties of this rock are such that recurrence of failure is very likely. A set of well developed joint planes dissects the granitic rock at about 42° north, which is less than the topographic slope and forms what might be considered as the sole or shear plane of the failure. The fractured condition of the granitic rocks might be attributed at least in part, to faulting that formed the lake basin and in part to the well developed joints that formed as tension cracks during release of overload pressure on the batholith by erosion.

Highway 89 is closed to traffic for several months each winter season because of snow and landslide conditions. The Division of Highways is constantly removing slide debris from the roadway, and the danger of renewed movement of slides in the area is ever present. Numerous other slides consisting mainly of mudflow or debris flow type (fig. 2B) occur in areas underlain by tertiary volcanic rock, mainly mudflow breccia. Birkeland, in studies of an area north of Lake Tahoe (1963-64), mapped several very extensive landslides along the Truckee River north of Tahoe City; one was more than 3 square miles in area.

In August 1967 a mudflow slide in the Second Creek drainage north of Lake Tahoe and west of Incline Village caused considerable damage to one home constructed essentially in the floodplain of Second Creek and damaged other structures less seriously. (Glancy, 1969).

Snow avalanche is a land instability process that has important implications in the Tahoe area. Winter travel and winter sports require significant alteration of the topography and consequently contribute to the hazard of avalanches. As development for these winter sports facilities and for mountain home construction increases, the likelihood of avalanches also increases. Planning for roadways and winter sports areas must include engineering geologic data to aid in delineating or defining areas that may be subject to avalanches. Study of hazards related to snow avalanches was not a part of this investigation and it is mentioned here only to emphasize the necessity for planners and developers to include this potential problem in their plans. Several good publications on this subject are included in the list of references of this report (U. S. Dept. Agriculture 1961 and 1967; and Hotchkiss, 1968).

The location of winter sports areas is related indirectly to another process of mass-wasting. These areas, especially ski areas, are commonly situated in glacially scoured canyons, and much of the natural erosion is controlled by glacial features. The most recent glaciation scoured away much of the older glacial debris and weathered rock of much of the canyon surfaces. The southern part of the basin is underlain mainly by granitic rocks, many of which have been scoured by glaciers and have been broken by joints (fractures). Where the geometry of the fractures is such that they intersect, the blocks have moved downslope to form talus deposits. Because of the danger of rockfalls, development below these areas should be avoided or carefully evaluated.

Other processes that add to problems of erosion or land instability in the basin are the loosening and spalling of rock as a result of frost action and forest fires. Because much of the basin area has high precipitation rates and low temperatures as well as joints or fractures in rock material, the combination of water, rock cracks, and freezing mechanically breaks off blocks of rock to facilitate mass-wasting and erosion. Similarly, forest fires (to a much less degree) by rapid changes of temperature can cause spalling of rock; however, this process is extremely rare and is restricted to areas where slopes are steep and have thick vegetative cover.

## FACTORS AFFECTING EROSION AND SEDIMENTATION

### Natural Processes

Much of the land area of the Lake basin is underlain by unstable or unconsolidated rock material that is readily eroded by surface runoff water. Sediment produced by runoff moves downslope into streams, where it is either deposited in the stream channel or is transported to the Lake. This sediment pollutes the Lake by contributing much of the fine silty material that contains nitrogen and phosphorus. Once the land area is disturbed by construction activities and the erosion cycle started, erosion will continue until a state of equilibrium is reached unless effective corrective measures are taken. Other criteria that will aid in determining erosion potential are precipitation rates and intensity (precipitation rates per unit of time). Unconsolidated, loosely, or poorly consolidated materials below steep slopes in high precipitation zones have high rates of erosion.

In the Lake Tahoe basin, decomposed granitic rocks is a major erosion and sedimentation problem. This rock unit when disturbed from its original form by construction activities or indirectly from construction activities, probably has the most severe erosional and subsequently severe sedimentation of tributary streams and Lake Tahoe proper. Rather vivid examples of this problem can be observed in the Heavenly Valley ski area where road, homesite, and ski developments have produced excessive erosion and sedimentation problems. Most of these areas of decomposed granite that are undisturbed have, to a degree, reached a state of natural stability; however, very minor disturbance can change this condition of relative equilibrium to one of very active or dynamic instability to erosive forces that eventually results in sedimentation in the Lake. Predominantly granitic glacial moraines show very similar weathering characteristics. Weakly consolidated lakebed and glacial outwash deposits are especially susceptable to erosion under two principal conditions:

1. They underlie the flat easily accessible areas.

2. They occur in areas containing active streams or rivers in the influence area of controlled drainage from higher elevation developments.

These lakebed deposits consist of clay and silt-size particles that are readily removed and transported by moving water. Cut slopes and fill slopes offer essentially no resistance to erosive forces. Since many areas of lakebed sediments constitute catchment basins for earlier erosion of upland areas, any disturbance of these sediments readily affects subsequent erosion and sedimentation.

In the north area of the Lake basin, the main rock units are volcanic, and the problem of weathering and rock decomposition is less widespread. The weakly indurated mudflow and tuff breccia volcanic rocks usually weather and decompose much as granitic rocks do, and they cause similar erosion problems; however, elevation and degree of slope here are less severe than in the southern area. These younger volcanic rocks have been exposed to the elements for a much shorter time than the granitic rocks, and their texture and mineralogy are such that many of those characteristics of the granitic rocks that aid or promote weathering are absent from the volcanic flow rocks. These criteria control the erodibility of the rocks; however, the problem of erosion in the north area is not one of rock type, but of types and thicknesses of soils derived from volcanic rocks. The soils are generally shallow (from a few feet to tens of feet deep), fine-grained (silt- to clay-size), and high in iron and magnesium but low in silica. These soils support dense vegetation and naturally resist erosion unless disturbed. Disturbance from construction or similar activities that remove protective vegetative cover generally progresses rapidly. The eroded material is readily transported to the Lake by streams, sheet flow, and other means.

Beyond the scope of this study, but important to understanding the problems involved in erosion and siltation, are data on the source, nature, volume, chemical and mineral composition, and rate of production of eroded material in the major and some of the minor drainages into the Lake. Tremendous volumes of naturally derived or eroded sediments enter the Lake, and, from the information noted above, it is necessary to determine, at least in a general way, the amount of man-generated silt entering the Lake.

Much of the naturally deposited sediments in the Lake, which seem to be from about 2,200 to 2,500 feet thick, are apparently nearly devoid of nutrients and are not sensitive to eutrophication. In contrast, the man-generated silt and the accelerated erosion caused by man's activities contribute sediments that contain varying amounts of nutrient-rich materials that accelerate eutrophication.

**Man-induced Processes**

Man-induced processes of erosion have been discussed in detail in other reports on the area. Only a short note on some of these processes and their relation to geology is included here.

The beginning of significant introductions of silt to the Lake can be attributed to logging and the construction of roadways and railways during the Comstock mining era. Later, in the 1930's and even in the 1950's, summer home and resort developments accelerated erosion. Shoreline construction, high elevation ski complexes, golf courses, roadways and other public works projects were constructed with little or no concern for geologic and soil conditions. Prevention of these man-caused erosion and sedimentation problems is the essential purpose for organizing a Bi-State Regional Planning Agency.

**Excessive Erosion**

Many parts of the Lake Tahoe basin are unstable because the rock materials are easily loosened and moved by flowing water. The sediment produced is dumped as a natural waste on lands below, works its way into streams, creates turbidity, and eventually is transported into the lake to be deposited as sediment that supplies nitrogen to the lake environment. The eroded land is a scar that is esthetically detracting and that is extremely difficult to control or use.

Erosion depends on two factors: water velocity and the ease with which particles can be picked up and suspended by the moving water. Water velocity is greatest and therefore produces the most erosion on steep slopes during the spring thaw and heavy rain storms. If water velocity is constant, the erodibility of a particular rock unit depends on several properties of the material. The size of individual particles or pieces within the rock unit is important because small grains are easily lifted and moved whereas large blocks are not. In addition to size, the way in which the individual particles are held in place or are protected from surface runoff affects erosion.

The large pieces and blocks of the metamorphic and glaciated granitic terrain decrease the erodibility of these rocks. Water often contributes to rockfalls by acting as a "lubricant" between adjacent blocks that have only marginal stability. Normal erosion is very slow, and areas of granitic corestones, diorite, and talus resist erosion. Most valcanic rock resists erosion because it breaks into large cohesive blocks; however, a small percentage of the tuff and mudflow breccias have eroded and formed extensive erosional mudflows. These mudflows originate from areas in which the rocks are not well cemented; so the presence of erosional mudflow deposits should be a warning against additional erosion in that vicinity.

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# APPENDIX I

## GENERAL FEATURES THAT AID RECOGNITION OF ENVIRONMENTAL PROBLEMS OF GEOLOGIC UNITS IN THE TAHOE BASIN AREA CALIFORNIA

**(Risk Potential: H = High, L = Low, M = Medium)**

| GEOLOGY MAP ROCK UNIT (Plate 1) | EROSION POTENTIAL | SILTATION POTENTIAL | SEISMIC HAZARD POTENTIAL | DEGREE OF CONSOLI-DATION | RELATIVE BEARING STRENGTH | STREAM CHANNEL STABILITY | NATURAL LANDSLIDE SLUMP OR ROCKFALL POTENTIAL | DISTURB. LANDSLIDE SLUMP OR ROCKFALL POTENTIAL | EXCAVATION (ripability) CHARAC-TERISTIC | SOURCE OF CONSTRUC-TION MATERIAL (fill) | SOIL CREEP |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Qta Talus | L - M | L - M | M - H | L | L - M | L | M - L | H | H | M - H | M - H |
| Qls Landslides & Rockfall | H | H | H | L | L | L | H | H | H | L - M | H |
| Rl Younger Lake Deposit | H | H | L - M | L - M | L - M | L - M | M - L | H | H | M - H | L - M |
| Qal Stream Alluvium | M - H | M | L - M | L - M | L - M | M - H | L | M | H | H | L |
| Ql Old Lakebed Deposit | M | M - H | L - M | L - M | L - M | M | L - M | M | H | M - H | L |
| Qg Glacial Outwash | M - H | M - H | L - M | L | L - M | M | L - M | M | M - H | H - M | L |
| $Qm^3$ Tioga Moraines | M - H | M - H | L - M | L | L - M | M - L | M | H - M | H - M | M - H | L - M |
| $Qm^4$ Tahoe Moraines | M - H | M - H | L - M | L - M | L - M | M - L | M | H - M | H - M | M | L - M |
| $Qm^5$ Pre-Tahoe Moraines | H | H | L - M | M | L - M | M | M | H - M | H | M - L | M |
| Qm Moraines Undiffer. | M - H | M - H | L - M | L - M | L - M | M - L | M | H - M | H | M | L - M |
| Qpvc Cinder cone; scoria | L - M | L - M | L - M | L | L - M | M | M | M | H - M | M | L |
| Qlt Lake & Fluvial Gravel & Alluvium | M | M - H | M | L - M | L - M | M - L | M | M - H | H | M - L | M |
| $Qv^I$ Intrusive volcanic rocks | L | L | L | H | H | H | L | L | L | H - M | L |
| $Qpv^l_1$ - $Qpv^l_4$ Latite & Basalt flow & $Qpv^b_1$ - $Qpv^b_2$ | L | L | L | H | H | H | L | L | L | H - M | L |
| Qpv & $Qpv^r$ Vol. flow undiff. & Rhyolite dome | L | L | L | H | H | H | L | L | L | H - M | L |
| $T^f$ Lake & Fluvial Dep | M | M - H | M - H | M - L | M | M | M | M | M | M - L | M |
| $Tc^v$ Vol. Conglom. & sandstone | M - L | M - L | M - L | M | M | M | M - L | M | M - L | M - L | M |
| $Tv^a$ Andesite and $Tv^b$ Basalt flows | H | L | L | H | H | H | L | L - M | L | M - L | L |
| $Tv^p$ Mudflow and tuff breccias | M - H | M - H | M | M - L | L | M - L | M | M - H | M - H | M | M |
| Ti Intrusive volcanic | L | L | L | H | H | H | L | L - M | L | M - H | L |
| $Tv^p_r$ Rhyolite tuff | M - H | M - H | M | M - L | M | L | M | M - H | H | L | M |
| Tv Volcanic: undiffer | M | M | M - L | M | M | M | M | M - H | M - H | M | M |
| $Mv^r$ Rhyolite tuff | L | L | M - L | H | H | H | L | M | L - M | M | L - M |
| $gr^a$ Alaskite & quartz Monzonite | L | L | L | H | H | H | L | L - M | L | M - H | L |
| $gr^g$ Granodiorite | L | L | L | H | H | H | L | L - M | L | M - H | L |
| $gr_g$ Glaciated granitic rocks | L | L | L | H | H | H | L | L - M | L | M - H | L |
| $gr_d$ Decomposed granitic rocks | H | H | L | L | L | L | M | H | H | L | H |
| $gr_c$ Granitic corestones | L | L | H - M | H | M - H | H - M | M | H | L - M | L - M | L - M |
| gr Granite undiffer. | L | L | L | H | H | H | L | L - M | L | M | L |
| di Diorite rocks | L | L | L | H | H | H | L | L - M | L | M - L | L |
| $Mv_1$ $Mv_2$ $Mv_3$ Metavolcanic rocks | L | L | L - M | H | H | H | L | M - H | L | M - H | L |
| $Ms_1$ $Ms_2$ $Ms_3$ $Ms_4$ $Ms_5$ $Ms_6$ $Ms_7$ Metasedimentary rocks | L | L | L - M | H | H | H | L | M - H | L | M - H | L |
| Mv Metavolcanic rocks undiffer. | L | L | L - M | H | H | H | L | M - H | L | M - H | L |
| Ms Metasedimentary rocks undiffer. | L | L | L - M | H | H | H | L | M - H | L | M - H | L |
| M Metamorphic rocks undiffer. | L | L | L - M | H | H | H | L | M - H | L | M - H | L |

# APPENDIX II

## EARTHQUAKE HAZARDS IN LAKE TAHOE BASIN[5/]

### History

Recorded earthquake history for the region surrounding Lake Tahoe began in 1860 with a destructive shock near Carson City. We know of one earthquake prior to 1860 from reports by Paiute Indians, who reported (to the Virginia City *Territorial Enterprise* in 1865) a great earthquake near Pyramid Lake in 1852 (Slemmons *et al.*, 1965). It is said to have opened great cracks in the ground from which water spouted 100 feet high and caused a large landslide on Slide Mountain, 6 miles north of Crystal Bay. It has been conjectured that a very young fault scarp at the base of the Carson Range in Carson Valley may have formed during this earthquake, but this would require that the shock be centered on the Sierra Nevada frontal fault. This is unlikely if one believes the Indians' report from Pyramid Lake, which strongly suggests the epicenter was much nearer there than Carson Valley.

Damaging earthquakes that occurred within 40 miles of Lake Tahoe before 1934 are listed below (table 2). Few instrumental determinations of epicenters of California earthquakes that occurred before 1934 are available; so locations given in table 2 are necessarily only approximate. Table 3 lists instrumentally determined epicenters for earthquakes with magnitude greater than or equal to 4.0 since 1934, and table 4 lists shocks located in Tahoe basin. Faults and locations of earthquakes since 1934 are plotted on a map of the region (fig. 5). Table 5 is an abridged version of the Mercalli Earthquake Intensity Scale published in 1931.

Until 1916, when the first seismograph was installed at the University of Nevada, the nearest instruments were located in Berkeley and on Mt. Hamilton, near San Jose. Thus, locally damaging earthquakes in Tahoe basin may have escaped detection prior to 1916. However, it is believed that since 1916 no damaging earthquakes in this area could have gone undetected.

Data presented in this paper show no earthquake with intensity greater than VI or magnitude above 5.0 in Tahoe basin since 1916, and the greatest *observed* intensity there due to earthquakes centered outside the basin is VI. Probably the great earthquakes of 1852, 1860, and 1869 had intensities greater than VI at Lake Tahoe. The shocks of 1860 and 1869, which were apparently centered in the Carson City-Virginia City area and had maximum intensities of IX, probably had intensities of VII or VIII at Lake Tahoe. The 1860 earthquake may have centered on the Sierra Nevada frontal fault about 6 miles from the east shore of the Lake; if so, the intensity there would have been VIII or IX.

It seems probable that Tahoe basin has experienced structurally damaging intensities (VII or higher) two or three times since 1852. Intensity VI has been observed four times and intensity V eighteen times since 1860 (Algermissen *et al.*, 1969, p. 41).

### Risk

Earthquake risk to structures is determined by the proximity, magnitude, and frequency of occurrence as well as by the dynamic response of near-surface earth materials underlying those structures. Risk is nearly always greater on soft wet ground and thick alluvial deposits than of firm dry or rock.

*Seismicity.*—Apparently the Tahoe basin has been an area of low seismicity for the past 110 years, but it is adjacent to two areas of moderate seismicity: the Sierra Nevada frontal fault and Carson Valley on the east; the Truckee basin and the Mohawk and Sierra Valleys to the north. The Sierra Nevada frontal fault is about 6 miles east of Lake Tahoe, and is considered to be active on the basis of earthquake epicenter locations in the region and the existence of a very young fault scarp at the base of the east side of the Carson Range. Lawson (1912) reported the vertical displacement to be about 44 feet along this fresh scarp, which is probably no more than several hundred years old. This means that great and destructive earthquakes have probably occurred on this frontal fault within the last several hundred years, and there is every reason to believe such earthquakes will occur in the future—how soon no one knows.

5/ By Roger Greensfelder, Associate Seismologist, California Div. of Mines and Geology, Sacramento.

Tahoe basin is a graben, i.e., a down-dropped block bounded by steep faults on either side. These faults are structurally concordant with, although not known to be connected to, faults to the north in the vicinity of Truckee basin, Sierra Valley, Grizzly Valley, and Mohawk Valley. A substantial number of earthquakes has been recorded in these areas (fig. 5). In 1966 a magnitude 5.8 earthquake occurred near Hobart Mills, about 13 miles north of Lake Tahoe, yielding intensity VI in the north shore area; in 1948 a magnitude 6.0 shock occurred about 5 miles west of Verdi, also with intensity VI at Tahoe.

A major earthquake with magnitude from 7 to 8 in or near Truckee basin would probably have intensity VII to IX in the North Shore area, and VI to VIII in the more distant South Shore area. Furthermore, such an earthquake probably would be accompanied by surface faulting over a distance of 40 or more miles, which could extend into Tahoe basin. On the basis of recorded earthquake history for this region, such an earthquake should be considered a probable occurrence.

Accurate prediction of the time and place of earthquakes is not yet possible; however, we can say approximately how frequently an earthquake of given magnitude can be expected per unit area in a region. In their analysis of seismicity in the western United States, Ryall *et al.* (1966, p. 1121) place the Tahoe Region within the Ventura - Winnemucca seismic zone, the most active of six seismic zones defined in their study. In this zone we may expect a shock of magnitude 7.0 once per 550 years per 1,000 square kilometers (Ryall, p. 1124). Therefore, the 5,000 sq. km. area lying within 25 miles of the center of Lake Tahoe may be expected to have one magnitude 7.0 shock every 110 years, on the average. Any such shock within this area would have an intensity between VI and IX in Tahoe basin, depending on epicentral distance and ground conditions. It should be emphasized that the earthquake recurrence interval used above is an average for a very large region, and the true values for various subregions may vary considerably.

*Effect of foundation earth materials.*—It has been learned that for an earthquake of given magnitude and epicentral distance, the intensity at a particular site is controlled by the character of near-surface and foundation earth materials. Intensity on soft, saturated alluvium or fill ground may be from one to three units higher than on underlying or adjacent hard rock, depending on the amplitude and predominant periods of the ground motion (Barosh, 1969). Extremely coarse alluvium (rock debris and gravel) and consolidated sediments exhibit less increased intensity or amplification than soft, wet, sandy and clayey alluvium.

Most commercial and many residential structures in Tahoe basin are founded on alluvium, lakebeds, or gracial outwash near lake level. These deposits are varying combinations of sand, gravel, silt, and clay which are mostly saturated at depths below a few feet. Areas underlain by these materials can be expected to have intensities from one to three units higher than areas underlain by hard rock (granite or volcanics) or glacial moraine. Furthermore, during a strong earthquake the soft, wet sediments may crack, lurch, settle, or liquefy; these effects pose a major threat to structures.

Therefore, building codes of Lake Tahoe communities should require that large commercial structures planned in areas underlain by soft sediments, as described above, meet standards of earthquake safety more stringent than those of the Uniform Building Code, which makes no allowance for added seismic risk due to soft ground conditions like those found around Lake Tahoe. Residential housing developments in these areas should also be required to meet these increased standards of seismic safety. This might be achieved largely by implementing improved foundation design and preparation.

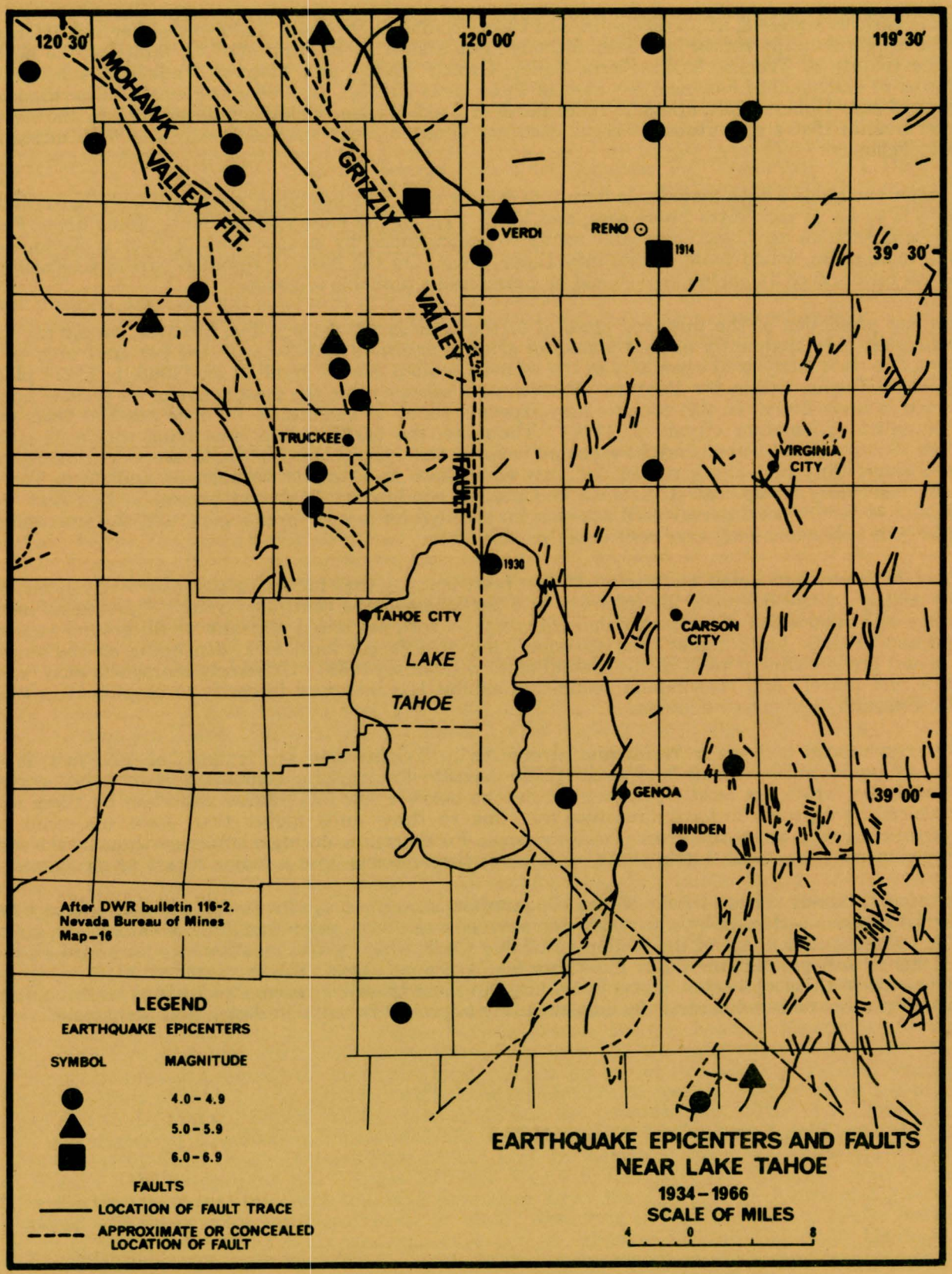


Figure 5.—Earthquake epicenters and faults near Lake Tahoe, 1934-1966 (from Wolfe, 1968.).

**Table 2.—Damaging earthquakes near Lake Tahoe since 1850[1/]**

| Date | Approximate epicenter | Intensity[2/] near epicenter | Damage and intensity |
|---|---|---|---|
| 1852 | Near Pyramid Lake, Nevada | X | Paiute Indians report earthquake near Pyramid Lake. Great cracks opened from which water spouted 100 feet into the air. Large landslide on Slide Mountain. |
| Mar. 15, 1860 | Carson Valley, Nevada | IX | Shaking was very violent in Carson City. It was felt over 250,000 sq. mi. |
| May 30, 1868 | North of Lake Tahoe | VII | Felt over 40,000 sq. mi. |
| Dec. 27, 1869 | Carson Valley, Nevada | IX | This shock probably occurred near Virginia City where brick buildings were damaged. Damage also reported at Steamboat Springs, Genoa, Carson City, and Downieville. |
| Jan. 24, 1875 | Mohawk Valley | VI | The shock was felt at Oroville and Downieville. Turner reported that ground fissures appeared near Wash post office in Mohawk Valley. |
| June 3, 1887 | Carson Valley, Nevada | VII | This shock occurred near Carson City. Stone and brick walls were cracked in the town. |
| June 22, 1909 | Sierra County | VII | The most strongly shaken region centered south or southeast of Downieville. Chimneys were damaged at Downieville. After-shocks continued for 10 days. |
| April 24, 1914 | Near Reno | VIII | Four chimneys at Univ. of Nevada and other chimneys in Reno were toppled. |
| April 9, 1930 | Near Lake Tahoe 39.2°N 120.0°W | VI | Plaster cracked in buildings near Lake Tahoe. Magnitude 4.3. |

1/ Based on data from John Wolfe (1968) and Slemmons *et al.* (1965).
2/ Modified Mercalli Intensity Scale.

**Table 3.—Instrumentally located earthquake epicenters near Lake Tahoe[1/]**

| Latitude Deg. | Min. | Longitude Deg. | Min. | Date Mo | Day | Yr | Quality* | Magnitude |
|---|---|---|---|---|---|---|---|---|
| 38 | 43 | 119 | 44 | 12 | 20 | 42 | B | 4.5 |
| 38 | 44 | 119 | 41 | 12 | 17 | 42 | C | 5.5 |
| 38 | 48 | 120 | 06 | 8 | 6 | 37 | D | 4.5 |
| 38 | 49 | 119 | 59 | 3 | 22 | 53 | A | 5.0 |
| 38 | 49 | 119 | 59 | 3 | 22 | 53 | B | 4.3 |
| 38 | 54 | 120 | 06 | 3 | 5 | 46 | | 4.1 |
| 39 | 00 | 119 | 54 | 3 | 28 | 48 | D | 4.6 |
| 39 | 02 | 119 | 42 | 10 | 2 | 62 | | 4.3 |
| 39 | 05 | 119 | 57 | 1 | 22 | 51 | B | 4.8 |
| 39 | 16 | 120 | 12 | 8 | 21 | 61 | B | 4.0 |
| 39 | 18 | 119 | 48 | 11 | 25 | 47 | C | 4.5 |
| 39 | 18 | 120 | 12 | 9 | 8 | 47 | B | 4.5 |
| 39 | 18 | 120 | 12 | 9 | 8 | 47 | B | 4.7 |
| 39 | 22 | 120 | 09 | 4 | 7 | 54 | B | 4.3 |
| 39 | 24 | 120 | 10 | 9 | 14 | 68 | | 4.6 |
| 39 | 25 | 119 | 47 | 5 | 9 | 52 | C | 5.1 |
| 39 | 26 | 120 | 09 | 9 | 12 | 66 | | 5.8 |
| 39 | 25 | 120 | 09 | 9 | 14 | 68 | | 4.5 |
| 39 | 26 | 120 | 24 | 3 | 30 | 43 | C | 5.3 |
| 39 | 28 | 120 | 20 | 5 | 29 | 54 | C | 4.1 |
| 39 | 30 | 120 | 00 | 8 | 7 | 44 | D | 4.2 |
| 39 | 32 | 119 | 59 | 9 | 26 | 53 | B | 5.3 |
| 39 | 33 | 120 | 05 | 12 | 29 | 48 | B | 5.0 |
| 39 | 30 | 120 | 05 | 1 | 8 | 49 | B | 4.3 |
| 39 | 33 | 120 | 05 | 1 | 20 | 49 | B | 4.8 |
| 39 | 34 | 120 | 18 | 10 | 1 | 58 | B | 4.6 |
| 39 | 36 | 120 | 18 | 5 | 10 | 47 | B | 4.2 |
| 39 | 36 | 120 | 28 | 11 | 18 | 60 | B | 4.4 |
| 39 | 37 | 119 | 42 | 10 | 26 | 50 | C | 4.2 |
| 39 | 37 | 119 | 48 | 1 | 21 | 51 | B | 4.1 |
| 39 | 38 | 119 | 41 | 11 | 10 | 50 | C | 4.0 |
| 39 | 40 | 120 | 33 | 6 | 14 | 59 | B | 4.5 |
| 39 | 42 | 119 | 48 | 7 | 8 | 49 | D | 4.5 |
| 39 | 42 | 120 | 06 | 10 | 30 | 59 | D | 4.1 |
| 39 | 42 | 120 | 24 | 6 | 22 | 50 | D | 4.1 |
| 39 | 43 | 120 | 12 | 4 | 1 | 59 | B | 5.6 |

* Quality: Relative accuracy of plot of epicentral locations.
A - Specially investigated
B - Probably within 5 kilometers
C - Probably within 15 kilometers
D - Very rough

1/ Data from John Wolfe (1968).

**Table 4.—Earthquake in Lake Tahoe Basin since 1930**

| Date | Epicenter | Intensity | Magnitude |
|---|---|---|---|
| April 9, 1930 | 39.2°N 120.0°W<br>Plaster cracked in houses near Lake Tahoe | VI | 4.3 |
| March 5, 1946 | 38.9°N 120.1°N<br>Bijou. Small objects overturned. | VI | 4.1 |
| January 22, 1951 | 29.1°N 119.95°W<br>Tahoe City | V | 4.8 |
| March 22, 1953 | 38.8°N 120.0°W<br>South of Meyers | V | 5.0 |
| March 22, 1953 | 38.8°N 120.0°W<br>Aftershock | V | 4.3 |

**Table 5.—Modified Mercalli earthquake intensity scale of 1931 (abridged)**

| | |
|---|---|
| I | Not felt except by a very few under especially favorable circumstances. (I Rossi-Forel Scale.) |
| II | Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing. (I to II Rossi-Forel Scale.) |
| III | Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibration like passing truck. Duration estimated. (III Rossi-Forel Scale.) |
| VI | During the day felt indoors by many, outdoors by few. At night some awakened. Dishes, windows, doors disturbed; walls made creaking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably. (IV to V Rossi-Forel Scale.) |
| V | Felt by nearly everyone; many awakened. Some dishes, windows, etc., broken; a few instances of cracked plaster; unstable objects overturned. Disturbances of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may stop. (V to VI Rossi-Forel Scale.) |
| VI | Felt by all; many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight. (VI to VII Rossi-Forel Scale.) |
| VII | Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in wall-built ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving motor cars. (VIII Rossi-Forel Scale.) |
| VIII | Damage slight in specially designed structures; considerable in ordinary substantial buildings, with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Disturbed persons driving motor cars. (VIII+ to IX Rossi-Forel Scale.) |
| IX | Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; great in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken. (IX+ Rossi-Forel Scale.) |
| X | Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed (slopped) over banks. X Rossi-Forel Scale.) |
| XI | Few, if any, (masonry) structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipelines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly. |
| XII | Damage total. Waves seen on ground surfaces. Lines of sight and level distorted. Objects thrown upward into the air. |

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# *APPENDIX III*

## GEOLOGIC CONSIDERATIONS IN LOCATING SITES FOR WASTE DISPOSAL[e/]

### Sewage Disposal

The geologic and hydrologic problems related to disposal of waste materials within the Lake Tahoe basin were, for practical purposes, well defined by the requirements for total export from the basin by December 1970. Subsequently the California Legislature passed Assembly Bill 1943, which requires that by January 1972 all sewage generated within the Tahoe basin be exported. Nevertheless, this waste created in the basin will have to be disposed of on land areas that are within economically feasible distance from the basin. This section of the report discusses this problem.

The report "Comprehensive Study on Protection of Water Resources of Lake Tahoe Basin Through Controlled Waste Disposal, 1963" very pointedly illustrated the need for removal of all sewage and solid waste products from the basin. It covered in great detail aspects of existing facilities for sewage disposal, design and operation of land disposal systems, and methods of disposal of effluent waste. Efforts to satisfy the requirement for exporting sewage and solid waste products have been pursued ever since appearance of that report.

An important section of the Tahoe study was directed toward developing geological information related to land disposal of both sewage and solid waste materials. Numerous areas have been investigated and some of them were comprehensively tested and evaluated as possible disposal sites. A major problem, if not the major problem in the Tahoe basin, is the prevention of chemical nutrients, mainly nitrates and phosphates, from entering Lake Tahoe. The principal contributor of these nutrients is sewage. Considerations of water quality, land use, aesthetics, and social conditions are all very important.

*South Lake Tahoe area.*—South Lake Tahoe area, that portion of the Tahoe basin having the major population center, the most extensive commercial development, and the area with the most rapid expansion, has through an excellent plan provided a solution to its sewage problem. A model tertiary sewage treatment plant produces a product of better quality than is required by the minimum U. S. Public Health standards for drinking water. However, since the treated effluent still contains nitrogen and phosphorus in concentrations that are detrimental to the Lake, which is highly sensitive to both these elements, the water is pumped over Luther Pass, some 1,500 feet above the lake, to a reservoir site in Alpine County about 35 miles southeast of the treatment plant. This 3,200 acre-foot Indian Creek reservoir is used for irrigation, as a source of water supply for fire suppression, and

e/ By Robert A. Matthews, geologist, California Division of Mines and Geology, Sacramento.

as a recreation area having water contact sports, boating, fishing and camping. The reservoir site is in an alluvium-filled valley that is underlain by granitic rocks. (Planning, site selection and evaluation for this site were completed prior to our involvement in the basin.)

The treatment plant has a capacity of 7.5 million gallons per day and a 60-million gallon holding pond to retain the effluent when waste waters do not meet quality standards for export. Sludge and solid waste material produced at the treatment plant must be transported out of the basin. These facilities were completed and in operation in April 1968.

*North Lake Tahoe area.*—The northern part of the Lake Tahoe basin has an entirely different sewage disposal problem. Two separate in-basin sewage disposal systems were operated by the Tahoe City and the North Tahoe Public Utility Districts. Both systems used land disposal ponds as their main means of disposing of waste.

Several plans for exporting sewage were proposed. The most comprehensive plans were presented in reports by Engineer Science, Inc. (1963-1965) and DeWante and Stowell in cooperation with Engineering Science, Inc. (1967). None of these plans have been used. In 1967, during the Department of Conservation's Coordinated Lake Tahoe Project, the California Division of Mines and Geology was requested to investigate possible sites for disposal of sewage for the North Tahoe area. They investigated possible interim and final sites, and prepared several reports of investigation and evaluation (Matthews, 1967 and 1968). Of the six sites studied, Site #6 (Cinder Cone) was selected by the various groups involved with the problem. Since this site, selected as the best potential interim disposal area, was situated near the basin drainage divide, extensive surface and subsurface investigations were required to determine the direction of subsurface movement of effluent disposed at the site. The procedures used were surface geologic mapping, shallow pit percolation testing, seismic refraction and magnometer surveys, core-hole drilling, bore-hole television observations, and packer and slug injection water testing.1/ Representatives from the Federal Water Pollution Control Administration, U. S. Forest Service, State Department of Conservation, Department of Water Resources, Regional Water quality Control Board, Placer County Departments of Public Health and Planning, Tahoe City and North Tahoe Public Utility Districts, and private groups and individuals all helped in the selection of the Cinder Cone Site.

Development of the site began in the fall of 1968, and operations on a limited basis began during the winter of 1969. In April 1970, Tahoe City Public Utility District began disposing of sewage at the rate of about 200,000 to about 350,000 gallons per day. At a later date, North Tahoe Public Utility District also began participating at a rate of about 500,000 to 1,350,000 gallons per day. Several problems related to construction of the disposal site were brought to the attention of the managers of the Public Utility Districts who are responsible for the operation of the site and these were scheduled for correction. The site was originally designed to handle 2 1/2 million gallons per day; however, in anticipation of increased disposal requirements, Franks (1970), Engineering Geologist for the State Water Resources Control Board prepared a report on the percolation rate and travel time estimates for discharge to the Cinder Cone Site. This report suggests that from computations to determine discharge area, the capacity of the Cinder Cone Site should be limited to about 2.8 million gallons per day. Testing was conducted in the field to determine the actual time-related percolation rates in order to determine the capacity of this facility (Franks, 1970).

The Cinder Cone Site will receive sewage generated in the North Tahoe area from Bliss State Park on the southwest, to Stateline on the northeast (including the gaming area discharges). The groups involved in the investigation, evaluation, and acceptance of the site intended that it should serve as an interim site pending development of a final site. Prior to and concurrent with studies and investigations for the interim site, we were involved in investigations to locate a final site. Plan B of the Engineering Science, Inc., study suggested a site in Martis Valley above Dry Lake; this site was included in Matthews' study (July 1968) on the Investigation of Seven Potential Effluent Disposal Sites in the Martis Valley Area for the Proposed North Tahoe - Truckee Regional Waste Management Plan. Sites VI and VII were considered for possible further comprehensive investigation and evaluation. In conjunction with this report, Forsberg (July 1968) prepared a hydrologic study, the "Martis Valley Waste Water Disposal Site Study," which included recommendations on hydrologic studies to be included in the evaluation of potential sewage disposal sites in this area.

1/ For specific reports on these tests, see the References section of this paper. For summary report and recommendations, see Matthews, 1968.

The Martis Valley Steering Committee (consisting essentially of the same groups involved in the Cinder Cone Site study) evaluated the reports and suggested that one or more of the seven sites investigated should be tested in detail to determine the potential as a final site. Strong objections to use of the approved sites in Martis Valley had been raised; and since development is planned here, these areas are probably eliminated. In 1969 a board consisting of five managers of the Public Utility Districts and comparable organizations held meetings and conducted studies to formulate a plan to initiate the evaluation of a final site. In March 1970, the Five Districts Committee prepared a draft — North Tahoe-Truckee Regional Sewage Plan-Work Program for Treatment and Disposal Study — which was designed to develop the most practical plan for treatment and disposal or reclamation of sewage. Several plans were considered — land disposal, direct discharge to the Truckee River and reservoir site or sites. It was suggested that preliminary reconnaissance and studies be made to determine the most promising alternative. To date no decision has been reached.

Some progress has been made towards investigating potential reservoir sites (Franks, personal communications), with the possibility of using the reclaimed waters for irrigating water-short areas in Sierra Valley or Long Valley north of the Tahoe basin. This plan is valuable as a water conservation measure, and the sale of such water may help to defray the high cost of treatment and export.

**Solid Waste Disposal**

*South Lake Tahoe area.*—The existing site for solid waste disposal for the southern part of the lake area is on U. S. Forest Service land east of Meyers. This site and one in the Glenbrook-Stateline area of Nevada process about 80 percent of the refuse generated in the Tahoe basin. The California site covers about 10 acres; however, as of June 1969, only about 3 acres was available for use in waste disposal. About 2½ years is the maximum life of this site, and the Forest Service permit will terminate in December 1971. Since the Forest Service is deeply involved in protection of the environment, it is not likely to renew the permit to operate this site but has allowed the county adequate time to find and develop an alternate disposal site outside the basin. Several studies of this problem have been made (Burnett, 1967; Department of Public Health, 1968). A site near Gardnerville, Nevada, has been selected and will be used as a regional site to care for the southern and southeastern part of the Lake Tahoe basin, including much of the eastern part of the basin in Nevada.

*North Tahoe area.*—Three disposal sites are being used for wastes generated in the North Tahoe area; however, the Tahoe City site, located about 1 mile northeast of Tahoe City, accepts most of the waste material generated. The original site was about 80 acres; in 1969 only about 25 acres of usable land remained. This site is being phased out; the timing is determined by the development of a larger out-of-basin regional disposal site.

The North Tahoe area has undergone extensive investigation of potential sites for solid waste disposal. Some 23 potential sites have been investigated by private, Federal, State, and County groups (Wilsey & Ham, 1960; Placer County, 1965; California Department of Public Health, 1969; Scribner, 1969, and Matthews, 1968 & 1970). Al Marino, Director of Environmental Health, Placer County, the State Department of Public Health, and other interested groups indicated that areas in Martis Valley near the proposed effluent waste disposal sites 6 and 7 could serve as a regional solid waste site. Subsequently, field investigations started by Placer County were centered around an area west of Truckee River a few miles south of Truckee, California. Preliminary investigation indicated that either Site 1 or Site 2 or both of them would be feasible as a regional waste disposal site. Placer County requested permission from the U. S. Forest Service to excavate test holes to determine the suitability of this area for land disposal of waste. Since data from this test program were favorable, Placer County submitted a request to the U. S. Forest Service for use of this land. A meeting was held with the various representatives involved with recommendations to test the subsurface to a depth of 30 feet and to determine whether ground water underlies the proposed site. The U. S. Forest Service's environmental Engineering Supplement-Minimum Standards for Sanitary Landfill and Modified Sanitary Landfill Solid Waste Disposal Sites (1969) and the Lahontan Regional Water Quality Control Board's Policy Regarding the Disposal of Solid Waste (1969) have set stringent requirements. Placer County, in cooperation with technical assistance from the Division of Mines and Geology, negotiated a contract with the Department of Water Resources to drill from six to twelve holes to a depth of 30 feet each. The study was organized and coordinated by the California Division of Mines and Geology. The subsurface study was completed and a report covering the investigation and evaluation was completed for Placer County in June 1970 (Matthews, 1970).

In conjunction with this study, Placer County Public Works Department began a preliminary road

survey to plan a high quality surfaced roadway to service the site. A topographic survey with the preparation of a 1" = 100' topographic map with a 2-foot contour interval was also completed and used in its preliminary form as a base map for the waste disposal site.

The high quality roadway required by the U. S. Forest Service will be expensive (probably more than $100,000) for Placer County, the developer of the site. However, it exemplifies the U. S. Forest Service's serious commitment to environmental protection. Factors considered in design of the road were grade, road cut slopes, aesthetic characteristics of roadway, and requirements for slope protection. In conjunction with geologic aspects of road construction, the Forest Service had in consultation a staff landscape architect to evaluate the proposed roadway and aid in insuring minimal scarring of the landscape and to use the topography and vegetation in screening the roadway from other road and recreational areas.

Following these investigations and suggestions from the report on the geologic investigation and evaluation of the disposal site, the U. S. Forest Service will issue a 15-year special use permit to Placer County for approximately 32 acres for a sanitary landfill operation. The principal advantage of this site over other sites considered is its utilization as a regional site to handle the solid waste generated in the North Tahoe basin from Stateline to Bliss State Park and the area along the Truckee River and including the area around Truckee, California. Placer County contracted with a civil and sanitary engineering firm to make an engineering report on the proposed land fill site. The completed report contained data on engineering considerations of roadway, water rights, refuse handling, and land fill operations (Landis, 1970).

Geologic studies of the surface and subsurface conditions were required before permission for use was granted; this indicated that the involved public agencies are actively engaged in protecting and preserving the natural environment. Prior to the exhaustion of space for disposal at this site (approximately 15 to 20 years), a more efficient and less contaminating or toxic method of disposal (such as high temperature incineration) probably will be economical and will permit return of this land to better use. Nevertheless, the land area upon termination of disposal or as sub-areas of this site are completed, will be reclaimed for recreational or open space land use (i.e., campgrounds, tree farms, or greenbelt).

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# GEOMORPHIC ANALYSIS OF THE LAKE TAHOE BASIN[1/]

Geomorphology (*geo-*, earth; *morpho-*, form; *-logy*, science) is the systematic study of the origin and nature of landforms. Equally important in the study of landforms are the processes and stages of development of those forms.

A geomorphic unit is an area of land that is homogeneous with respect to the nature and intensity of natural processes. Such areas are delineated on the basis of homogeneity of geology, topography, climate, soils, vegetation, and hydrologic characteristics. Geomorphic units have strong life zone connotations. Actually they are ecologic land systems and therefore represent the most logical unit for land use management.

The interaction of controlling factors within each system tends to give rise to a characteristic assemblage of such natural processes as soil erosion, mass movement, and stream cutting. If changes are made in system variables, each process interacts with the others and, in turn, conditions the type of response that is probable in the system. Each geomorphic unit can be regarded as a separate process-response model, which has primary relevance in distinguishing the land use capability of each system.

These systems represent a somewhat sensitive dynamic equilibrium with respect to erosion processes. In many areas, natural forces have worked toward establishment of relatively stable slopes and channels. Such balances are often extremely delicate. Failure to recognize the nature of the balance and, consequently, the limits of disturbance permissible before such balances are upset, has led to marked increase in the rates of landsliding and other erosional processes. Apart from the utter disruption of the slope environment, such abnormal erosion has inevitably contributed increased debris to streams, and thereby increased both flooding and a serious deterioration in water quality.

An understanding of natural processes is essential to land use management of the Lake Tahoe basin. This has become increasingly clear in recent years where, under natural conditions, geomorphic units with varying erosion thresholds occur and where artificial changes in vegetation and soil resulting from fire, deforestation, excessive grazing, road building, and other developments have introduced a new element to the environment. By directing attention to the whole landscape assemblage, rather than to single component parts (e.g., soil), we may recognize geomorphic units within which the intensity and relative significance of the various processes are, according to our present information, essentially uniform. The uses of these units in regional planning are important for the following reasons:

1. Geomorphic analysis stratifies the landscape into recognizable units through integration of several complex variables. These can be analyzed for frequency of occurrence of various processes. By this means the planner can isolate critical processes (e.g., stream cutting, soil erosion, landsliding, etc.) and can predict the likelihood and magnitude of their occurrence after various levels of land disturbance. He is thus able to formulate questions which must be answered before planning policy is possible. The geomorphic unit can be used, therefore, as a guide for identifying the need for more detailed information which should be synthesized as a basis for a decision on land use alternatives such as to avoid certain areas completely or to limit disturbance to those levels which are below the expected erosion threshold.

2. Geomorphic units provide a contextual framework by which other parameters of the system may be analyzed and related to one another. For example, rapid erosion on steep slopes over a long period of time produces shallow soils that have low water-holding capacity and results in low potential for revegetation when these slopes are disturbed. In addition, the significance of slope as a source of potential energy for runoff and erosion varies, depending on the nature of the erosion process and the resistance to erosion within the geomorphic unit.

3. The recurrence of a specific type of geomorphic unit, regardless of location, implies a recurrence of the basic characteristics of that unit. Thus research results from plots can be extrapolated on a unit basis for units having similar characteristics so as to better define their performance when disturbed.

1/ Study by Dr. Robert G. Bailey, hydrologist, Lake Tahoe Basin Planning Team.

4. By gaining some understanding of the processes operating within the various geomorphic units, and by planning and working within a framework of these natural systems, land planners and managers may be better able to modify the impacts of development before they occur.

## GEOMORPHIC GROUPS

For the above reasons, the Lake Tahoe basin has been divided into six major geomorphic groups as follows:

A. Glaciated granitic uplands

B. Glaciated volcanic flowlands

C. Streamcut granitic mountain slopes

D. Streamcut volcanic flowlands

E. Depositional lands

F. Oversteepened slopes

These geomorphic groups are relatively large areas of land that have similar characteristics and serve to delineate the permanent element of the ecosystem. A number of closely related landforms exists within each major group. A detailed description of the geomorphic groups is given below in "Geomorphic Units." Description of their salient natural features and processes follows:

## A. *GLACIATED GRANITIC UPLANDS*

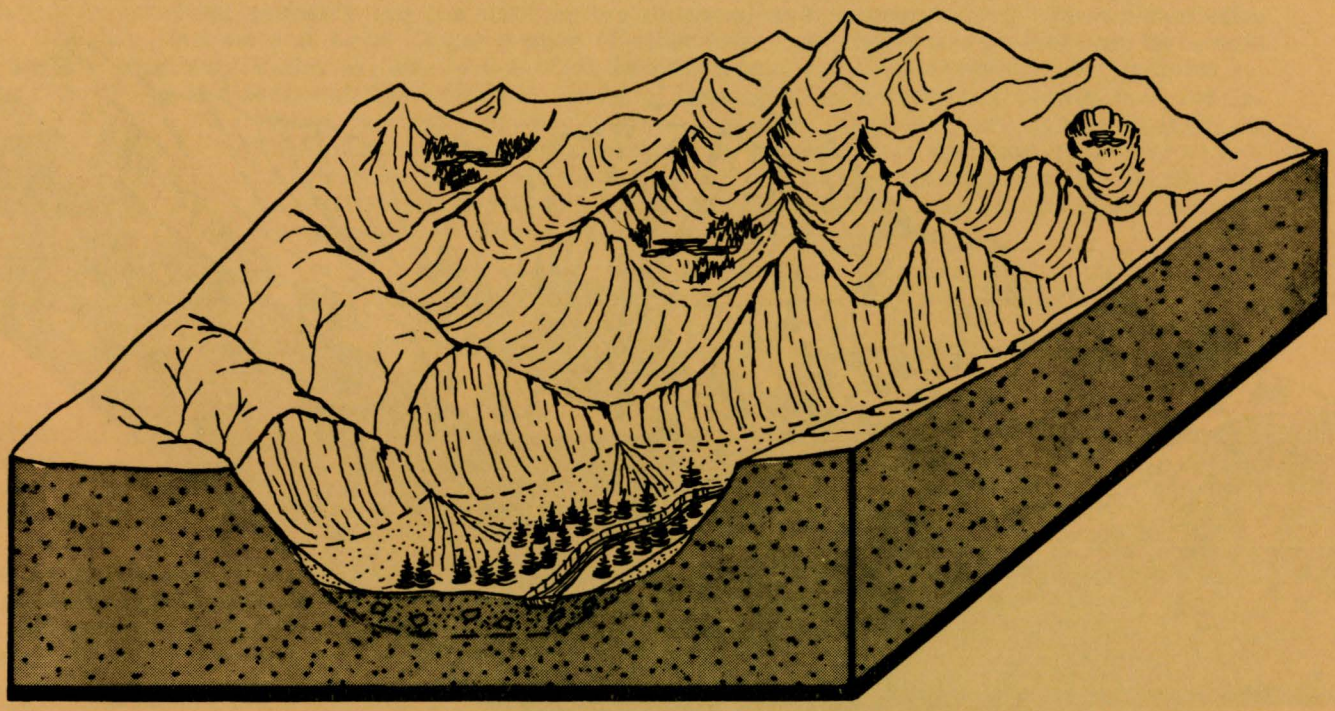
Location: South and southwest crest zone of the Sierra Nevada; also, the Desolation Wilderness.

Extent: 33,920 acres; 16.2 percent of Tahoe basin.

Topography: Mountainous uplands, cirques, glacial troughs, colluvial slopes, outwash. Many slopes are steep (50-70%); some are vertical.

Elevation: 7,000 to 10,000 feet.

Geology: Hard massive granite (mainly unweathered) with some joints, foliation, or fractures. Small areas of metamorphic rock representing roof pendants are included in this type.



Soils: Areas with this type have enough rock outcrop, rock rubble, or stones and boulders without or within very shallow soil (less than 10 inches) material to dominate completely the areal extent of the type. Rock outcrops comprise from 50 to 90 percent of the area.

Climate: Cool to cold; humid. MAT 40 to 42°F. MAP 40 to 60 inches.

Vegetation: Vegetation is sparse; most of the area is barren. Some scrub trees, shrubs, and forbs constitute the alpine vegetation.

Processes: Mudflows and landslides are numerous because of oversteepening by glaciation. Vigorous freezing and thawing of melt water causes frost shattering of the rock walls and produces fragments which move by gravity to form talus slopes. Talus flows, debris avalanching, rock glaciers, and rockfalls move debris from oversteepened slopes into bordering stream valleys. Cloudburst floods transport coarse sediment in stream channels and frequently produce mudflows and flood rock that reach canyon mouths.

Limiting land use qualities: Slope stability hazards, high runoff potential, and revegetation problems.

B. *GLACIATED VOLCANIC FLOWLANDS*

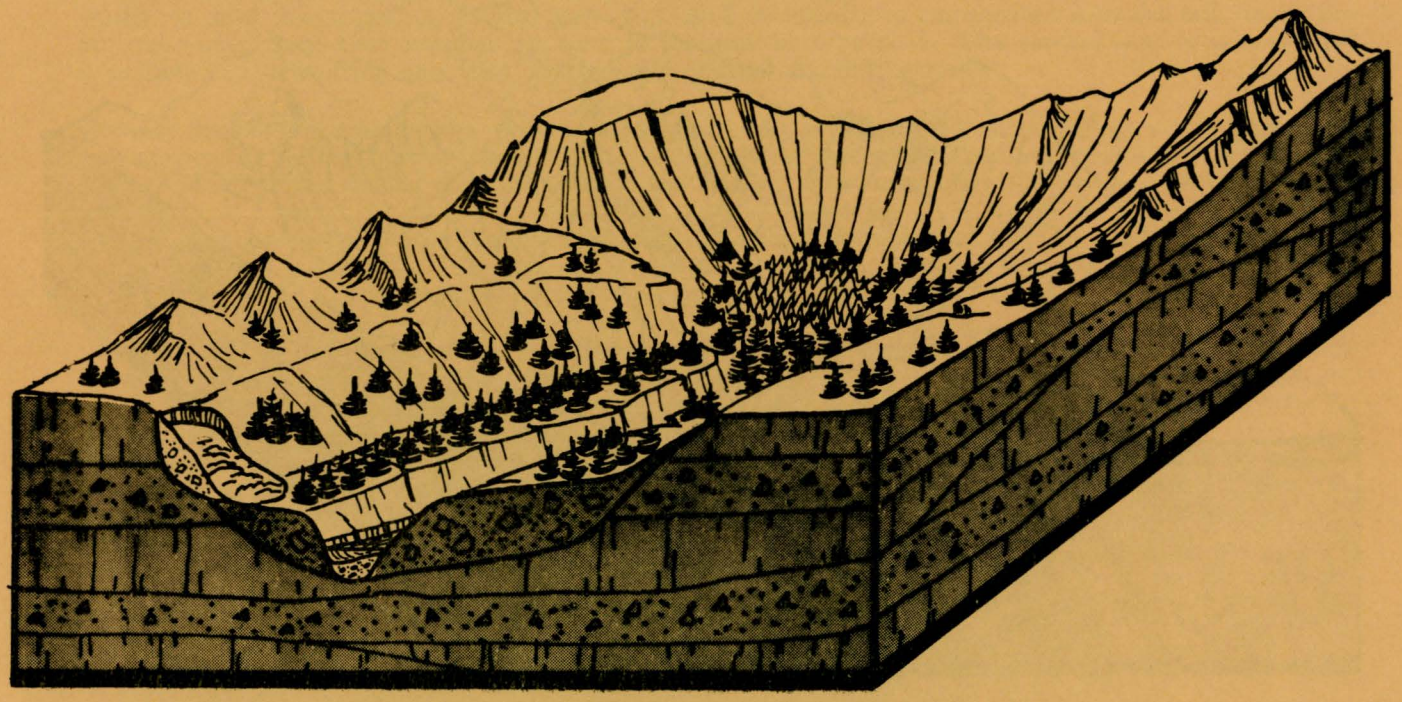
Location: Ward and Blackwood Creeks

Extent: 9,870 acres; 4.9 percent of area.

Topography: Topography varies from steep (30 to 50%) volcanic ridgelands with large cirque basins at the heads of major drainages to gentle slopes in valley bottoms. Hummocky morainal debris fills major stream valleys. Streams have trenched the debris forming shallow canyons.

Elevation: 6,800 to 9,500 feet.

Geology: Hard volcanic rocks of Tertiary age in loose to well cemented matrix (mainly mudflow and tuff breccia). Andesite flows are included. Glacial till is in valley bottoms and plastered on the sides of glaciated canyons.



Soils: Rock outcrops with a very thin soil mantle occur on the rocky ridgelands and on the cirque walls. Downslope from these areas are well drained, cobbly coarse sandy loams. Depth of soils in these areas ranges from 20 to 40 inches. Permeability of subsoil is moderately rapid. Runoff is rapid. The available moisture holding capacity is about 3 to 6 inches.

Climate: Cool to cold; subhumid to humid. MAT 40 to 42°F. MAP 35 to 80 inches.

Vegetation: Natural vegetation consists of red fir, white fir, mountain hemlock, and western white pine. Large areas along ridges and cirque basin walls are barren or support only sparse alpine type vegetation. Wet meadows are along valley bottoms.

Processes: Main processes are landslides on steep slopes, particularly where such slopes are overlain by glacial till and are undercut by stream erosion. Active stream cutting produces most of the sediment derived from this type since soil erosion is not important. Snow avalanching is active on steep northerly aspects, particularly along cirque walls.

Limiting land use qualities: Slope stability hazard, channel erosion, high runoff potential.

## C. *STREAMCUT GRANITIC MOUNTAIN SLOPES*

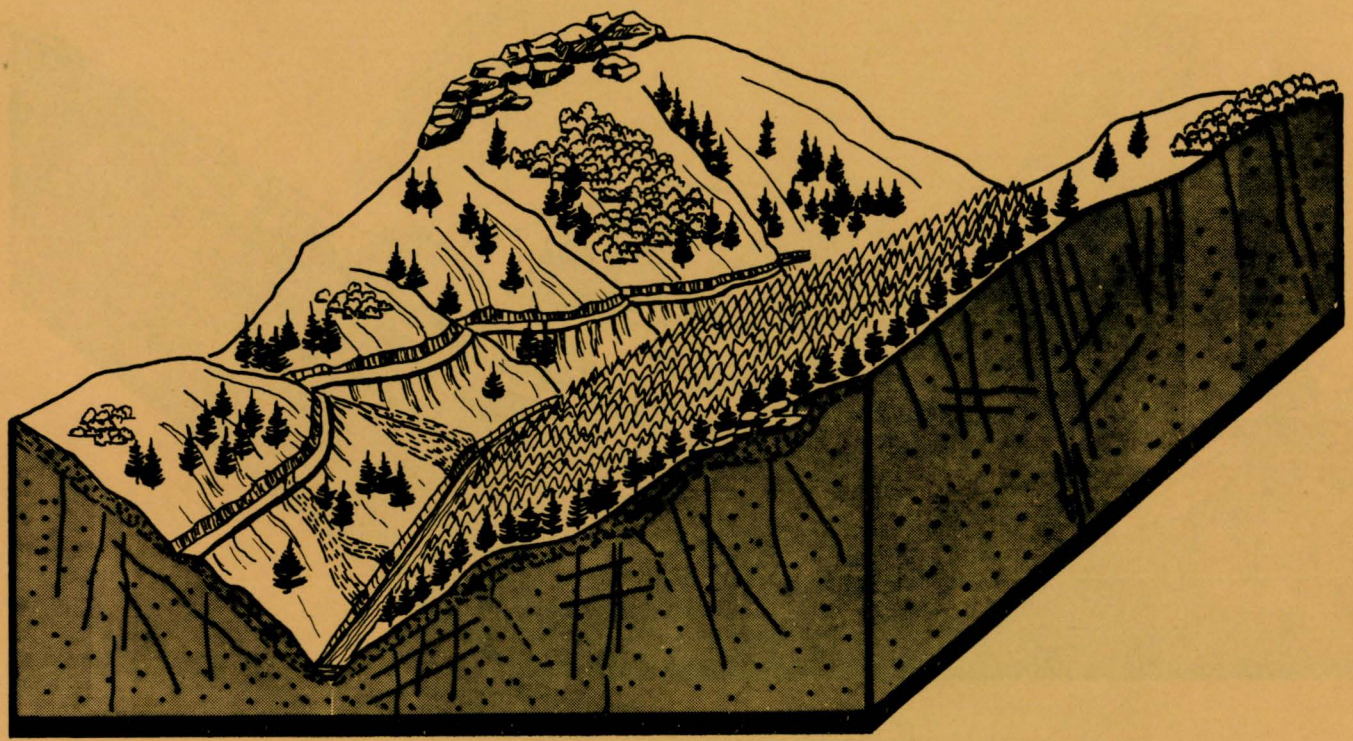
Location: Carson Range.

Extent: 64,880 acres; 32.1 percent of area.

Topography: This area consists mainly of steep (30 to 70%) slopes with minor valley flats. Stream erosion has dissected the area into an intricate arrangement of V-shaped canyons with numerous intermittent drainage channels. Some areas have been denuded of soil by accelerated erosion on oversteepened slopes. Ridgetops are relatively flat and stable but provide high runoff that actively erodes stream channels and forms gullies.

Elevation: 6,500 to 9,000 feet.

Geology: Massive granitic rocks overlain by a thick mantle of grus (decomposed granite in place). Rounded corestones or undecomposed cores of jointblocks are commonly embedded in the grus.



Soils: Soils of this type are excessively drained, very rocky, loamy coarse sands. Rock outcrops occupy about 10 to 25 percent of the area. The soils are generally thin, highly erodible, and have low fertility. Available water holding capacity is low (1 to 3 inches), and runoff is rapid.

Climate: Cool to cold; semiarid to subhumid. MAT 40 to 42° F. MAP 20 to 35 inches. There are strong differences in microclimate and vegetation between north- and south-facing slopes.

Vegetation: Semi-dense to dense stands of mixed conifers and pure pine, mostly Jeffrey pine, red fir, white fir, mountain hemlock, and western white pine. Pinemat manzanita and huckleberry oak make up the shrub understory. Chaparral grows on old burns. Sagebrush is common on drier sites.

Processes: Main processes are varied types of soil erosion, especially on denuded slopes. Concentration of water from flood runoff produces gully and channel erosion. Undercutting of slopes results in gravitational movement of the grus to the immediate channel forming dry creep cones. This gravitational debris is periodically flushed from the channel during storm or snow-melt runoff.

Limiting land use qualities: Soil erosion, channel erosion, high runoff potential, and fire hazard.

## D. *STREAMCUT VOLCANIC FLOWLANDS*

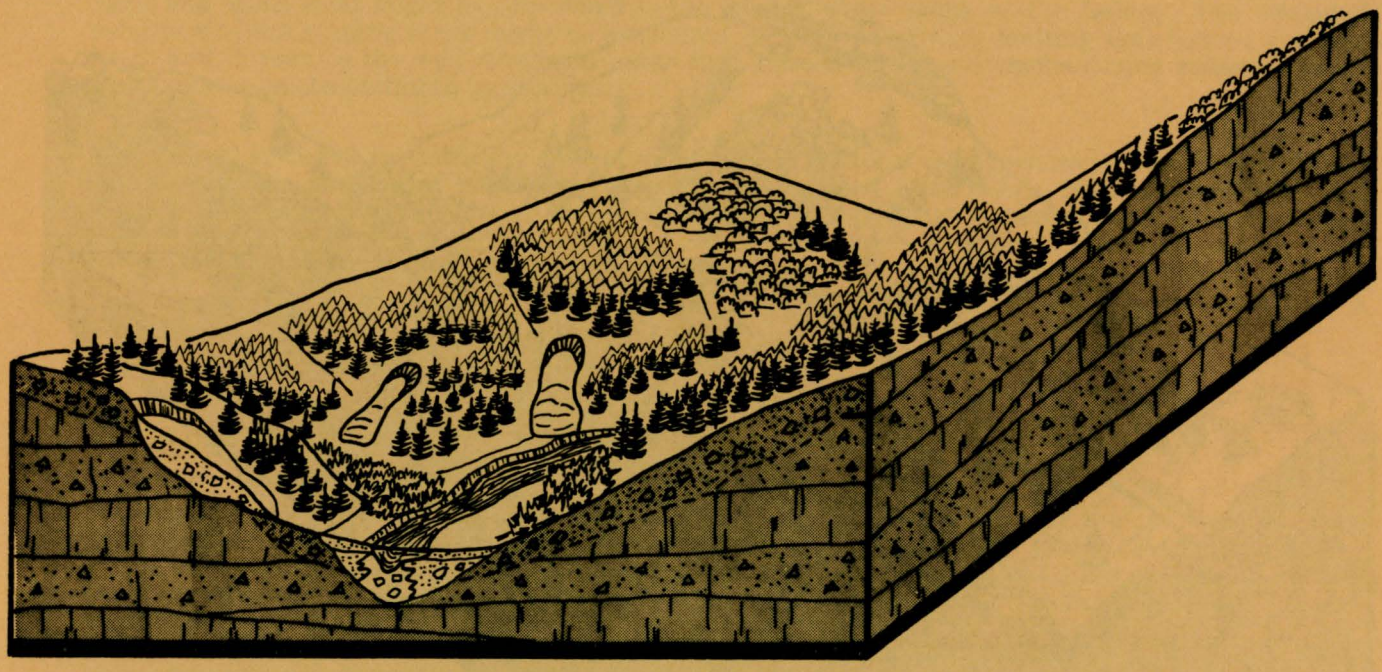
Location: North and northwest sides of the basin.

Extent: 23,640 acres; 11.7 percent of area.

Topography: Gentle mountain slopes and partially opened valleys. Ridgetops and stream valleys are generally rounded. Slopes range from 2 to 50 percent.

Elevation: 6,300 to 8,000 feet.

Geology: Extrusive volcanic rocks of Quaternary age underlie the more gentle slopes near the Lake. In the headlands, the bedrock is Tertiary volcanic rock (mainly mudflow and tuff breccia).



Soils: At higher elevations (above 7,600 feet) soils are shallow and stony and have low moisture storage capacities (1 to 3 inches). Below this elevation, soils are composed of sandy loams, 4 to 5 feet deep with 30 to 50 percent rock content. Their water holding capacities are about 3 to 6 inches . In contrast to other areas in the basin, these soils have the highest inherent fertility and lowest erosion hazard.

Climate: Cool to cold; subhumid to humid. MAT 40 to 42° F. MAP 25 to 45 inches.

Vegetation: Dense to semi-dense forest stands are evenly distributed over the area. Fir grows at the higher elevations, and mixed conifers are at lower elevations near the Lake.

Processes: Important processes are deep-seated landsliding (mainly slumping). Deep, fine-textured soils locally have high water tables. Sparse vegetation and shallow soils in the headlands periodically produce high runoff; this causes stream cutting and flooding in the lower parts of the drainages.

Limiting land use qualities: Low slope stability and flood hazards.

E. *DEPOSITIONAL LANDS*

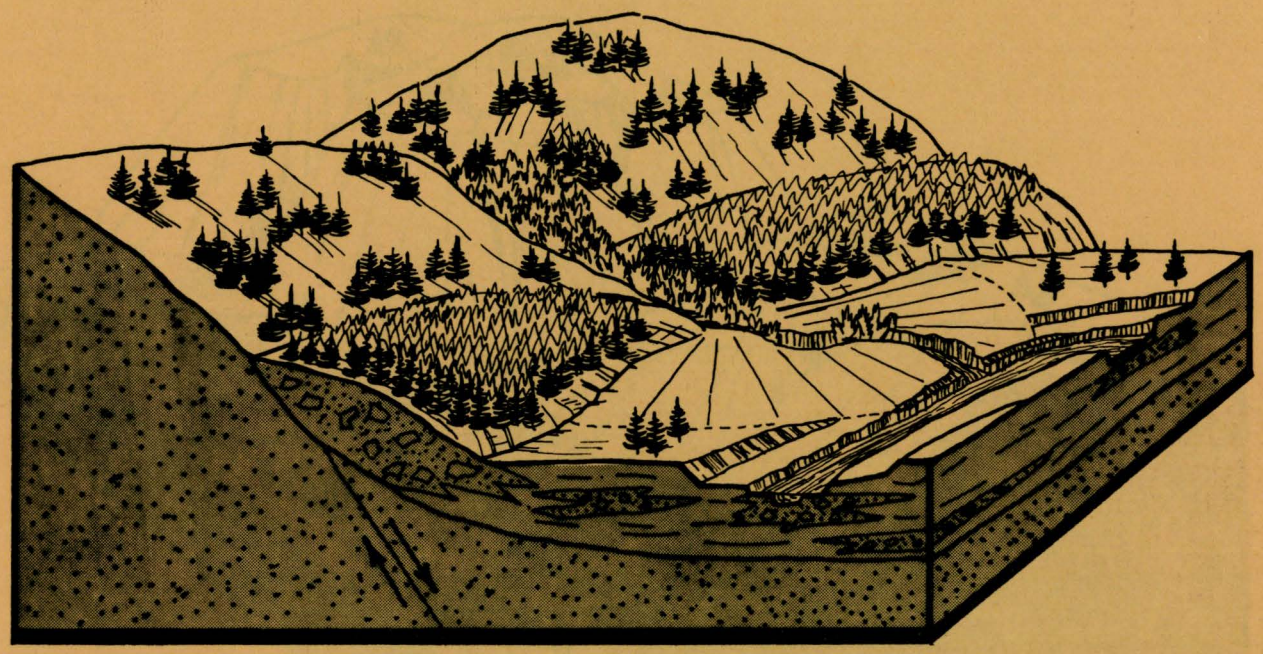
Location: Valley bottoms and plains; predominantly at south end of basin.

Extent: 62,090 acres; 30.6 percent of area.

Topography: Nearly level to moderately sloping (30%) outwash fans, terraces, floodplains, and moraines. Moraines rise 100 to 300 feet above the valley floor and have the greatest local relief. Streams are entrenched into these deposits and form a series of low terraces.

Elevation: 6,300 to 7,300 feet.

Geology: The geologic base varies from unstratified bouldery till to coarse sandy outwash and recent fine-grained alluvial deposits along stream channels and meadow bottoms. Included are lake deposits of variable gradation up to about 6,700 feet.



Soils: Soils are generally good, moderate to deep, and moderate in natural fertility; but low-lying areas have poor natural drainage and are subject to occasional flooding and ponding. All have a high water table. Moraines have thinner soils with moderate to high erosion potential.

Climate: Cool to cold; semiarid to humid. MAT 40 to 42° F. MAP 20 to 45 inches.

Vegetation: Moraines are covered by dense stands of mixed conifers and pines including Jeffrey pine, western white pine, and lodgepole pine; also white fir, red fir, greenleaf manzanita, and mountain whitehorn. Poorly drained areas have wet meadow associations. Vegetation on the outwash plains is mainly lodgepole pine; some Jeffrey pine grows in drier areas. Alluvial lands are dominated by herbaceous and riparian vegetation.

Processes: Main processes are landsliding on oversteepened morainal slopes, uneven settling of alluvial deposits, channel erosion and flooding, and meandering of perennial streams. Alluvial lands are the most ecologically sensitive in terms of wildlife habitat standpoint. These areas, because of the availability of an efficient transport mechanism (i.e., live water streams) produce high sediment yields when disturbed. This sediment is relatively rich in nutrients as compared to streamcut granitic mountain slopes.

Limiting land use qualities: Gully erosion, channel erosion, flood hazard, and seismic hazard.

F. *OVERSTEEPENED SLOPES*

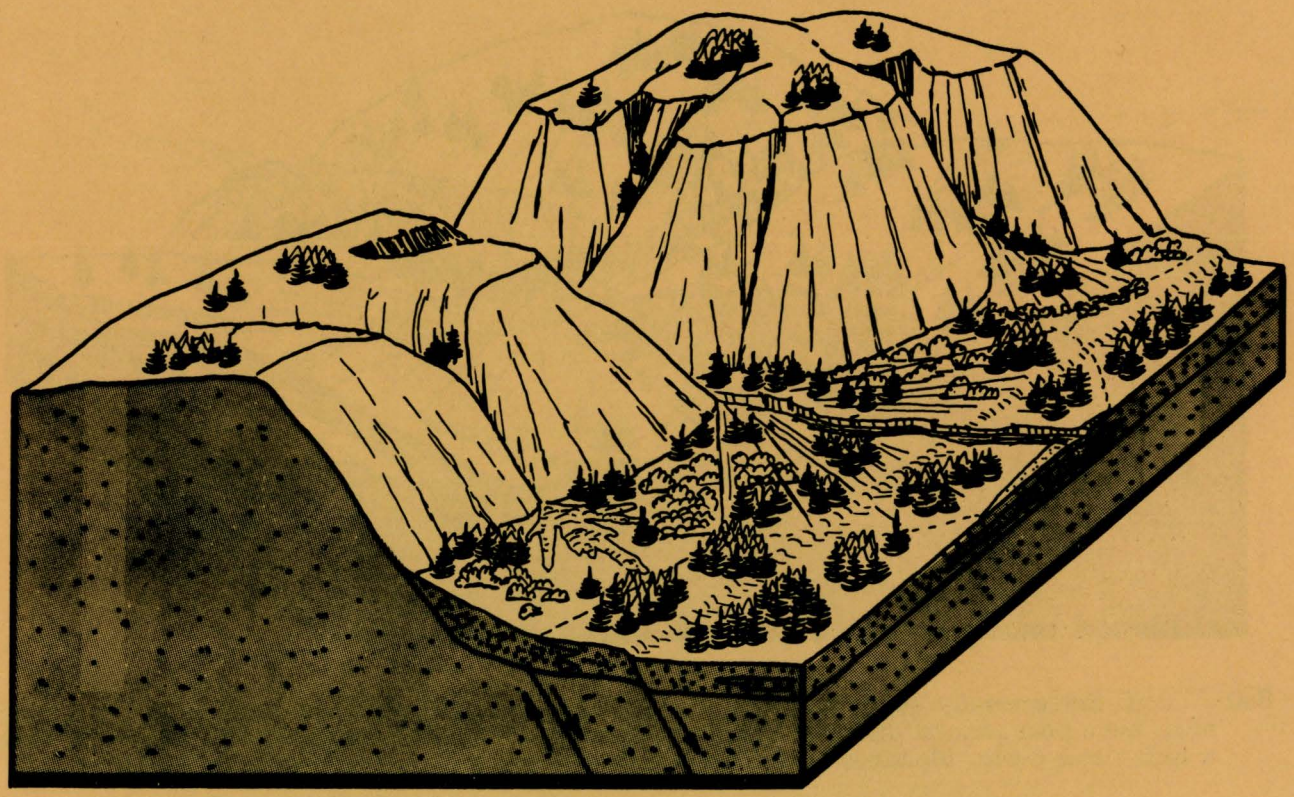
Location: Scarp running from Echo Summit to Emerald Bay; Truckee River outlet.

Extent: 8,020 acres; 3.9 percent of area.

Topography: Precipitous fault scarps and narrow canyons. Slopes are very steep (greater than 70%); some are vertical.

Elevation: 6,400 to 9,700 feet.

Geology: Hard competent rocks generally consisting of either glaciated granite, metamorphic, or intrusive volcanic rocks.



Soils: Most of this type is dominated by rock outcrops, rock rubble, talus, and rockslide debris with small inclusions of shallow soil (less than 10 inches).

Climate: Cool to cold; humid. MAT 40 to 42° F. MAP 40 to 45 inches.

Vegetation: Vegetation is sparse; the majority of the type is barren. Conifers and herbaceous types are found along canyon bottoms and spring outcrops.

Processes: Mudflows and landslides are larger and occur more frequently in this unit than any other in the basin. Mass gravity movement of rock and soil is accelerated where slopes are disturbed. Snow avalanches are common.

Limiting land use qualities: Slope stability hazards, runoff potential, and revegetation problems.

## GEOMORPHIC UNITS

Geomorphic groups are subdivided into geomorphic units, which represent variations of the group theme.

The geomorphic unit is the basic unit of this report. These units have soils, vegetative, and hydrologic characteristics that can be readily interpreted to identify hazards, suitabilities, and productivity potentials that are reliable for broad planning purposes. The 14 geomorphic units identified for this study and included on the geomorphic unit map are:

**Glaciated Granitic Uplands**

A Glaciated granitic uplands

**Glaciated Volcanic Flowlands**

$B_1$ Glaciated volcanic flowlands

$B_2$ Rocky ridge lands

**Streamcut Granitic Mountain Slopes**

$C_1$ Strongly dissected lands

$C_2$ Steep strongly dissected lands

$C_3$ Moderately dissected weakly glaciated lands

$C_4$ Subalpine rim lands

**Streamcut Volcanic Flowlands**

$D_1$ Toe slope lands

$D_2$ Headlands

**Depositional Lands**

$E_1$ Moraine land undifferentiated

$E_2$ Outwash, till, and lake deposits

$E_3$ Alluvial lands

**Oversteepened Slopes**

$F_1$ Canyon lands

$F_2$ Escarpment lands

The problem of how to identify and inventory the natural processes within each unit was solved by differentiating micro-landform and soil variations that indicate natural processes. These smaller areas which subdivide the geomorphic units are soil-landform types as delineated and defined by the Soil Conservation Service (1970).

This section includes a summary description of each geomorphic unit (Table 1) containing the following information[1/]:

1/ Detailed data on slope, rock type, soil association, soil type, and vegetation type are presented in Tables 2 through 6 in the Appendix.

**Map Symbol**

Symbol for the geomorphic unit as delineated on the Geomorphic Units map.

**Geomorphic Unit**

Gives the name of the unit. Under the name, the unit is divided into major soil associations as defined by the Soil Conservation Service (1970). Parentheses denote symbol used on General Soil Map. The soil associations differ from each other by having contrasting properties or by differing in potentials. For example, one association may be dominated by deep soils but another may have mostly shallow soils; or one association might be steeper than another.

**Percent of Unit**

Percent of the geomorphic unit represented by that soil association. Miscellaneous soil associations with minor percentages make up the remainder.

**Slope**

This column gives the range in percent for the slope gradient.

**Substratum or Parent Material**

Gives the name of the weathered bedrock or transported material on which the soil developed.

**Soil Texture**

Classification name of soil by texture according to the Soil Survey Manual of the U. S. Department of Agriculture.

**Effective Soil Depth**

Inches to restrictions such as weathered bedrock or cemented horizons.

**Available Water Capacity**

Total available water holding capacity within effective soil depth. "Available water" as used here represents the water which may be taken up from the soil by a plant.

**Hydrologic Soil Group**

Hydrologic soil groups are used in watershed planning in estimating runoff. Four groups are used, based on soil properties that influence runoff. These properties are depth to a high water table, intake rate, permeability after prolonged wetting, and depth to a layer of slow permeability. The influence of ground cover is treated independently and is not considered in making hydrologic groupings.

*Group A*: Soils have high infiltration rates even when thoroughly wetted and consist chiefly of deep, well to excessively drained coarse-textured soils. These soils have a high rate of water transmission and have low runoff potential.

*Group B*: Soils have moderate infiltration rates even when thoroughly wetted and consist chiefly of moderately deep and deep, moderately well and well drained soils, with moderately fine and moderately coarse textures. Soil permeabilities are moderately slow to moderately rapid. These soils have a moderate rate of water transmission and have moderately low runoff potential.

*Group C*: Soils have slow infiltration rates when thoroughly wetted and consist chiefly of well drained and moderately well drained soils with slowly and very slowly permeable layers. These soils have a slow rate of water transmission and have moderately high runoff potential.

*Group D*: Soils have very slow infiltration rates when thoroughly wetted and consist chiefly of shallow soils over nearly impervious materials or soils with high permanent water tables. These soils have a very slow rate of water transmission and have high runoff potential.

**Relative erosion potential**

The relative hazard of loss of soil from the surface by running water. It represents the combined effect on the soil of slope, climate, and erodibility. Soil erodibility is based on the detachability and transportation of soil particles, infiltration, and permeability of the soil. Slope (length and shape) and climate are evaluated and integrated into the erosion potential. In making erosion ratings, it is assumed that the vegetation cover is removed and the soil bare.

*High*: Unprotected bare soil erodes sufficiently to severely and permanently damage the productive capacity of the soil or yields excessively high volumes of sediment.

*Moderate*: Sufficiently resistant to erosion to permit limited and temporary exposure of bare soil during development or use.

*Slight*: No appreciable hazard of surface erosion.

## Table 1.—Geomorphic Unit - Soil Interpretive Groupings

| Map symbol | Geomorphic unit | Percent of unit | Slope | Substratum or parent material | Soil texture | Effective soil depth | Available water capacity | Hydrologic soil group | Relative erosion potential |
|---|---|---|---|---|---|---|---|---|---|
| | | | Percent | | | Inches | Inches | | |
| A | *Glaciated Granitic Uplands* | | | | | | | | |
| | 1. Granitic Rockland (H-1) | 73 | - | Granodiorite | - | <20 | <1 | D | Slight |
| $B_1$ | *Glaciated Volcanic Flowlands* | | | | | | | | |
| | 1. Waca (E-9) | 51 | 30-50 | Andesitic tuff | Cobbly coarse sandy loam | 20-40 | 3-6 | C | High |
| | 2. Waca (E-8) | 14 | 9-30 | Andesitic tuff | Cobbly coarse sandy loam | 20-40 | 3-6 | C | Moderate |
| | 3. Volcanic Rockland (H-1) | 10 | - | Andesitic tuff | - | <20 | <1 | D | Slight |
| $B_2$ | *Rocky Ridge Lands* | | | | | | | | |
| | 1. Volcanic Rockland (H-1) | 88 | - | Andesitic tuff | - | <20 | <1 | D | Slight |
| $C_1$ | *Strongly Dissected Lands* | | | | | | | | |
| | 1. Cagwin (D-3) | 52 | 30-70 | Weathered granodiorite | Very rocky loamy coarse sand | 20-40 | 1-3 | B | High |
| | 2. Toem (D-5) | 22 | 30-70 | Weathered granodiorite | Very rocky gravelly coarse sand | <20 | <1 | C | High |
| | 3. Cagwin (D-2) | 13 | 15-30 | Weathered granodiorite | Very rocky loamy coarse sand | 20-40 | 1-3 | B | High |
| $C_2$ | *Steep Strongly Dissected Lands* | | | | | | | | |
| | 1. Toem (D-5) | 49 | 30-70 | Weathered granodiorite | Very rocky gravelly coarse sand | <20 | <1 | C | High |
| | 2. Cagwin (D-3) | 26 | 30-70 | Weathered granodiorite | Very rocky loamy coarse sand | 20-40 | 1-3 | B | High |
| | 3. Granitic Rockland (H-1) | 8 | - | Granodiorite | - | <20 | <1 | D | Slight |
| | 4. Cagwin (D-2) | 7 | 15-30 | Weathered granodiorite | Very rocky loamy coarse sand | 20-40 | 1-3 | B | High |
| $C_3$ | *Moderately Dissected Weakly Glaciated Lands* | | | | | | | | |
| | 1. Cagwin (D-3) | 35 | 30-70 | Weathered granodiorite | Very rocky loamy coarse sand | 20-40 | 1-3 | B | High |

## Table 1.—Geomorphic Unit - Soil Interpretive Groupings—continued

| Map symbol | Geomorphic unit | Percent of unit | Slope | Substratum or parent material | Soil texture | Effective soil depth | Available water capacity | Hydrologic soil group | Relative erosion potential |
|---|---|---|---|---|---|---|---|---|---|
| | | | Percent | | | Inches | Inches | | |
| | 2. Toem (D-5) | 27 | 30-70 | Weathered granodiorite | Very rocky gravelly coarse sand | <20 | <1 | C | High |
| | 3. Granitic Rockland (H-1) | 13 | - | Granodiorite | - | <20 | <1 | D | Slight |
| | 4. Cagwin (D-2) | 8 | 15-30 | Weathered granodiorite | Very rocky loamy coarse sand | 20-40 | 1-3 | B | High |
| $C_4$ | *Subalpine Rim Lands* | | | | | | | | |
| | 1. Rockland (H-1) | 70 | - | | - | <20 | <1 | D | Slight |
| | 2. Toem (D-4) | 9 | 9-30 | Weathered granodiorite | Very rocky gravelly coarse sand | <20 | <1 | C | High |
| | 3. Shakespeare (E-11) | 8 | 9-30 | Metamorphic | Gravelly loam | >40 | 3-6 | C | Moderate |
| $D_1$ | *Toe Slope Lands* | | | | | | | | |
| | 1. Tahoma-Jorge (E-1, E-2) | 40 | 2-15 | Weathered volcanic | Very stony sandy loam | >40 | 3-6 | B | Slight |
| | 2. Jorge-Tahoma (E-3) | 16 | 15-30 | Weathered volcanic | Very stony sandy loam | >40 | 3-6 | B | Moderate |
| | 3. Umpa-Fugawee (E-5) | 16 | 2-15 | Hard fractured andesite | Very stony sandy loam | 20-40 | 1-3 | C | Slight |
| | 4. Jorge-Tahoma (E-4) | 6 | 30-50 | Weathered volcanic | Very stony sandy loam | >40 | 3-6 | B | High |
| $D_2$ | *Headlands* | | | | | | | | |
| | 1. Umpa (E-7) | 28 | 30-50 | Hard fractured andesite | Very stony sandy loam | 20-40 | 1-3 | C | High |
| | 2. Umpa-Fugawee (E-6) | 17 | 15-30 | Hard fractured andesite | Very stony sandy loam | 20-40 | 1-3 | C | Moderate |
| | 3. Volcanic Rockland (H-1) | 15 | - | Andesite | - | <20 | <1 | D | Slight |
| | 4. Jorge-Tahoma (E-3) | 9 | 15-30 | Weathered volcanic | Very stony sandy loam | >40 | 3-6 | B | Moderate |
| | 5. Umpa-Fugawee (E-5) | 6 | 2-15 | Hard fractured andesite | Very stony sandy loam | 20-40 | 1-3 | C | Slight |
| | 6. Tahoma-Jorge (E-1, E-2) | 6 | 2-15 | Weathered volcanic | Very stony sandy loam | >40 | 3-6 | B | Slight |
| $E_1$ | *Moraine Land Undifferentiated* | | | | | | | | |
| | 1. Tallac (C-5) | 10 | 0-9 | Glacial outwash with cemented pan | Gravelly coarse sandy loam | >40 | 3-6 | C | Slight |

**Table 1.—Geomorphic Unit - Soil Interpretive Groupings—continued**

| Map symbol | Geomorphic unit | Percent of unit | Slope | Substratum or parent material | Soil texture | Effective soil depth | Available water capacity | Hydrologic soil group | Relative erosion potential |
|---|---|---|---|---|---|---|---|---|---|
| | | | Percent | | | Inches | Inches | | |
| | 2. Meeks (C-3) | 9 | 15-30 | Cemented gravelly moraine | Very stony loamy coarse sand | >40 | 1-3 | C | High |
| | 3. Poorly drained soils (A-1) | 8 | - | Alluvium | Coarse sand to silt loam | >40 | 3-6 | D | Slight |
| | 4. Meeks (C-4) | 8 | 30-60 | Cemented gravelly moraine | Very stony loamy coarse sand | >40 | 1-3 | C | High |
| | 5. Tallac (C-7) | 7 | 15-30 | Moraine with cemented pan | Very stony coarse sandy loam | >40 | 3-6 | C | Moderate |
| | 6. Tallac (C-8) | 7 | 30-60 | Moraine with cemented pan | Very stony coarse sandy loam | >40 | 3-6 | C | High |
| | 7. Tallac (C-6) | 6 | 9-15 | Moraine with cemented pan | Stony coarse sandy loam | >40 | 3-6 | C | Slight |
| | 8. Meeks (C-2) | 5 | 5-15 | Cemented gravelly moraine | Very stony loamy coarse sand | >40 | 1-3 | C | Moderate |
| | 9. Meeks (C-1) | 4 | 0-5 | Cemented gravelly moraine | Stony loamy coarse sand | >40 | 1-3 | C | Slight |
| $E_2$ | *Outwash, Till and Lake Deposits* | | | | | | | | |
| | 1. Elmira-Gefo (B-1) | 19 | 0-9 | Outwash fans or moraines | Gravelly loamy coarse sand | >40 | 3-6 | A | Slight |
| | 2. Tallac (C-5) | 13 | 0-9 | Outwash with cemented pan | Gravelly coarse sandy loam | >40 | 3-6 | C | Slight |
| | 3. Jabu-Inville (B-3) | 12 | 0-9 | Outwash with cemented pan | Coarse sandy loam | >40 | 3-6 | C | Slight |
| | 4. Inville (B-5) | 9 | 0-9 | Alluvial fans and terraces | Stony coarse sandy loam | >40 | 3-6 | B | Slight |
| | 5. Poorly drained soils (A-1) | 9 | - | Alluvium | Coarse sand to silt loam | >40 | 3-6 | D | Slight |
| | 6. Cagwin (D-1) | 9 | 5-15 | Weathered granodiorite | Very rocky loamy coarse sand | 20-40 | 1-3 | B | Moderate |
| | 7. Cagwin (D-2) | 6 | 15-30 | Weathered granodiorite | Very rocky loamy coarse sand | 20-40 | 1-3 | B | High |
| | 8. Jabu (B-4) | 4 | 9-20 | Outwash terrace | Coarse sandy loam | >40 | 3-6 | C | Moderate |
| $E_3$ | *Alluvial Lands* | | | | | | | | |
| | 1. Poorly drained soils (A-1) | 28 | - | Alluvium | Coarse sand to silt loam | >40 | 3-6 | D | Slight |

## Table 1.—Geomorphic Unit - Soil Interpretive Groupings—continued

| Map symbol | Geomorphic unit | Percent of unit | Slope | Substratum or parent material | Soil texture | Effective soil depth | Available water capacity | Hydrologic soil group | Relative erosion potential |
|---|---|---|---|---|---|---|---|---|---|
| | | | Percent | | | Inches | Inches | | |
| | 2. Elmira-Gefo (B-1) | 14 | 0-9 | Outwash fans or moraines | Gravelly loamy coarse sand | >40 | 3-6 | A | Slight |
| | 3. Cagwin (D-3) | 7 | 30-70 | Weathered granodiorite | Very rocky loamy coarse sand | 20-40 | 1-3 | B | High |
| | 4. Jabu-Inville (B-3) | 3 | 0-9 | Outwash with cemented pan | Coarse sandy loam | >40 | 3-6 | C | Slight |
| $F_1$ | *Canyon Lands* | | | | | | | | |
| | 1. Jorge-Tahoma (E-4) | 51 | 30-50 | Weathered volcanic | Stony sandy loam | >40 | 3-6 | B | High |
| | 2. Volcanic stone and (H-2) | 23 | - | Volcanic | - | <20 | <1 | C | Slight |
| | 3. Volcanic Rockland (H-1) | 11 | - | Volcanic | - | <20 | <1 | D | Slight |
| $F_2$ | *Escarpment Lands* | | | | | | | | |
| | 1. Granitic Rockland (H-1) | 70 | - | Granodiorite | - | <20 | <1 | D | Slight |
| | 2. Cagwin (D-3 | 9 | 30-70 | Weathered granodiorite | Very rocky loamy coarse sand | 20-40 | 1-3 | B | High |
| | 3. Meeks (C-4) | 9 | 30-60 | Cemented gravelly moraine | | | | | |

## HAZARD GROUPINGS OF GEOMORPHIC UNITS

The land of the Lake Tahoe basin has been separated into fourteen recurring reconnaissance-level geomorphic units. These fourteen units have been divided into three broad groups that aggregate the units by a combination of land characteristics that identify the hazard potential probability. The major hazards for these lands are floods, landslides, high water tables, fragile soil-plant relations, and easily erodible soils; the whole area has been classified as high-, moderate-, and low-hazard lands, as described below. Some of the characteristics affecting the hazards are the depth to the water table, occurrence of floods, soil texture, slope gradients, climate, and the depth to bedrock. The grouping in this system is based on the magnitude of the hazards that are encountered. The magnitude considers the degree of the hazard relative to other hazards found on all units; the percentage and pattern of the hazardous land within a unit and the versatility of the land to sustain a multitude of activities without conflict to the land.

**Group I — High-hazard Lands** (122,160 acres)

On a Group I geomorphic unit, one or more of the above-mentioned potentially hazardous situations exist. The land characteristics of a particular geomorphic unit are quite uniform in having the same potential hazard over much of its area. Because of this uniformity, trying to avoid hazardous situations by proper location of a conflicting activity is more difficult on Group I lands than on the lands of the other groups.

These lands are not hazardous for all activities, but are limiting for more activities than Group II or Group III lands. They also conflict most with activities which disturb the soil.

Group I Geomorphic Units are:

| | | | |
|---|---|---|---|
| A | Glaciated granitic uplands | $C_3$ | Moderately dissected weakly glaciated lands |
| $B_1$ | Glaciated volcanic flowlands | $C_4$ | Subalpine rim lands |
| $B_2$ | Rocky ridge lands | $E_3$ | Alluvial lands |
| $C_1$ | Strongly dissected lands | $F_1$ | Canyon lands |
| $C_2$ | Steep strongly dissected lands | $F_2$ | Escarpment lands |

**Group II — Moderate-hazard Lands** (51,060 acres)

Group II geomorphic units also have hazardous characteristics, but differ from Group I lands by not having these characteristics uniformly distributed over the area. Hazardous areas are a smaller percentage of these lands and tend to be obvious and scattered so that land-disturbing activities have a good chance of avoiding them through careful location. There is a better opportunity for a wider variety of activities on Group II lands than on the Group I lands because of the lower percentage of hazardous areas. High impact activities (e.g., road construction) which are most disturbing to the landscape can be designed to occupy the more stable portions of these lands.

Group II geomorphic units are:

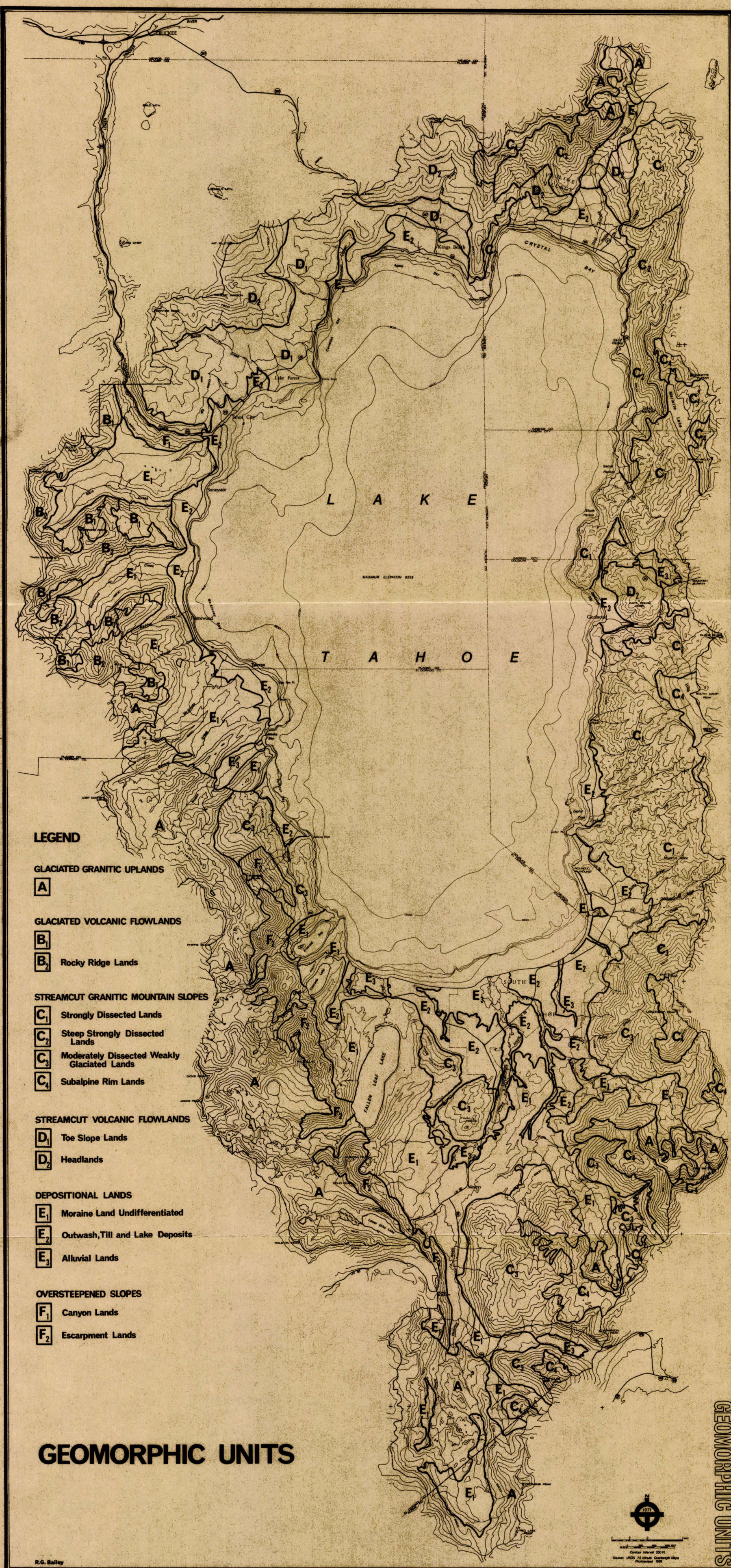
| | | | |
|---|---|---|---|
| $D_2$ | Headlands | $E_1$ | Moraine land undifferentiated |

**Group III — Low-hazard Lands** (29,200 acres)

Group III is the least fragile of the geomorphic units. Hazardous areas are minor; so there is better chance to avoid them. These lands can support the widest range of activities, but care must be taken to avoid abusing them. Even on these lands, project sites need to be checked for hazards by a land scientist.

Group III geomorphic units are:

| | | | |
|---|---|---|---|
| $D_1$ | Toe slope lands | $E_2$ | Outwash, till, and lake deposits |




# GEOMORPHIC UNITS

R.G. Bailey

GEOMORPHIC UNITS

# LAKE TAHOE REGION

**TAHOE REGIONAL PLANNING AGENCY**

**USDA FOREST SERVICE**

## APPENDIX

**Table 2.—Slope distribution by percent of geomorphic unit**

| Slope range* | Geomorphic units | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A | $B_1$ | $B_2$ | $C_1$ | $C_2$ | $C_3$ | $C_4$ | $D_1$ | $D_2$ | $E_1$ | $E_2$ | $E_3$ | $F_1$ | $F_2$ |
| percent | | | | | | | | | | | | | | |
| 0- 5 | 4 | 1 | 1 | 4 | 1 | 1 | 2 | 14 | 2 | 21 | 51 | 77 | 1 | |
| 6-10 | 9 | 3 | 1 | 13 | 4 | 5 | 5 | 36 | 8 | 20 | 29 | 11 | 9 | |
| 11-15 | 12 | 11 | 6 | 20 | 4 | 10 | 11 | 27 | 19 | 19 | 12 | 5 | 2 | 1 |
| 16-20 | 14 | 20 | 8 | 21 | 8 | 13 | 13 | 13 | 20 | 14 | 5 | 4 | 8 | 1 |
| 21-25 | 14 | 20 | 11 | 17 | 10 | 15 | 13 | 5 | 21 | 10 | 2 | 1 | 15 | 2 |
| 26-30 | 13 | 14 | 14 | 11 | 14 | 14 | 12 | 3 | 14 | 7 | 0 | 0 | 12 | 6 |
| 31-35 | 10 | 10 | 16 | 7 | 14 | 12 | 12 | 2 | 8 | 4 | 0 | 1 | 19 | 8 |
| 36-40 | 8 | 7 | 17 | 3 | 13 | 10 | 9 | 0 | 4 | 2 | | 0 | 15 | 12 |
| 41-45 | 6 | 7 | 14 | 1 | 11 | 7 | 8 | | 2 | 1 | | 0 | 9 | 13 |
| 46-50 | 4 | 2 | 7 | 0 | 8 | 6 | 5 | | 1 | 1 | | | 5 | 18 |
| 51-55 | 3 | 3 | 5 | 0 | 6 | 4 | 3 | | | 0 | | 0 | 2 | 14 |
| 56-60 | 2 | 0 | 1 | 0 | 3 | 2 | 3 | | 0 | 0 | | | 1 | 9 |
| 61-65 | 0 | | 0 | | 2 | 1 | 2 | | | 0 | | 0 | 2 | 7 |
| 66-70 | 0 | | | | 1 | 0 | 1 | | | | | | | 5 |
| 71-75 | 0 | | | | 0 | 0 | | | | | | | | 3 |

Note: 0 indicates less than 0.5%.

* Slope data were obtained from computer summaries of slope for each 10-acre cell within the unit.

**Table 3.—Rock type by percent of geomorphic unit**

| Rock type* | Geomorphic Units | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A | $B_1$ | $B_2$ | $C_1$ | $C_2$ | $C_3$ | $C_4$ | $D_1$ | $D_2$ | $E_1$ | $E_2$ | $E_3$ | $F_1$ | $F_2$ |
| Gr | 70 | | 1 | 94 | 95 | 94 | 77 | | 7 | 5 | 25 | 8 | | 59 |
| M | | | 2 | 4 | 1 | | 9 | | | | | 1 | | |
| Ms | 3 | 10 | 7 | | | 2 | | | 4 | 0 | 0 | 0 | | 3 |
| Mv | 9 | | | | | | | | | 0 | | | | 16 |
| Qal | 0 | | | 0 | | | | | 0 | 1 | 0 | 5 | | |
| Qg | | | | 0 | | | | | | 0 | 39 | 14 | | |
| Ql | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 3 | 1 | 2 | 28 | 27 | | 1 |
| Qls | 0 | | | | | 0 | 0 | | | | | | | 1 |
| Qlt | | | | | | | | | | | 1 | | | |
| Qm | 5 | 5 | 0 | | 1 | 1 | 1 | | | 81 | 3 | 2 | | 11 |
| Qmf | | | | | | | | | | 0 | | | | |
| Qpv | | | | 0 | 0 | | 0 | 68 | 1 | 0 | 0 | | | |
| Qpvc | | | | | | | | 0 | | | | | | |
| Qs | | | | | | | | | | | | | | |
| Qta | 0 | | | | | | | | | 0 | | | | 5 |
| Qu | | | 0 | | | 0 | | | | 0 | | 1 | | |
| Qv | | 1 | 0 | | | | | 5 | | 0 | 0 | 0 | | |
| Rl | | | | 0 | | | | | 0 | 0 | 1 | 41 | | |
| Tc | | | | | | | | | | | | | | |
| Ti | | | | | | | | | 0 | | | | | |
| Tv | 9 | 84 | 86 | 2 | 2 | | 11 | 23 | 86 | 1 | 0 | 0 | | |
| Di | 3 | | | | | 2 | | | | 0 | | | | 5 |
| Qg + Qm | | | | | | | | | | 1 | 0 | | | |
| Ql + Qg | | | | | | | 1 | | 0 | 2 | 1 | | | 0 |
| Qm3 + Qm4 | | | 3 | | | | 0 | | 1 | 5 | 0 | | | |

Note: 0 indicates less than 0.5%.

*Source: Matthews, R. A., and J. L. Burnett. 1971. Geologic map of the Lake Tahoe Basin *in* Geology for land use planning in the Lake Tahoe Basin. Calif. Div. of Mines and Geology. (Map in pocket)

#Data Missing.

**Table 4.—Percentage of soil associations by geomorphic units**

| Soil associations* | Geomorphic Units | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A | $B_1$ | $B_2$ | $C_1$ | $C_2$ | $C_3$ | $C_4$ | $D_1$ | $D_2$ | $E_1$ | $E_2$ | $E_3$ | $F_1$ | $F_2$ |
| A-1 | 1 | 1 | | 1 | | | | 2 | 1 | 8 | 9 | 28 | 1 | |
| B-1 | | | | | 1 | | | | | 1 | 19 | 14 | | |
| B-2 | | | | | | | | | | 3 | 1 | | | |
| B-3 | | | | | | 1 | | 4 | | 2 | 12 | 3 | | |
| B-4 | | | | | | 2 | | | | 2 | 4 | | | |
| B-5 | | | | | | | | | | | 9 | | | |
| B-6 | | | | | | | | | 1 | 1 | 2 | | | |
| C-1 | | | | | | | | | | 4 | | | | |
| C-2 | 1 | | | | | 1 | | | | 5 | | | | |
| C-3 | 6 | | | | 1 | 2 | | | | 9 | | 1 | | |
| C-4 | 4 | | | | | 1 | | | | 8 | | 3 | | 9 |
| C-5 | | | | | | 1 | | | | 10 | 13 | 1 | | |
| C-6 | | | | | | 1 | | | | 6 | 2 | | 3 | |
| C-7 | 4 | | 1 | | | 1 | | | | 7 | 1 | | | |
| C-8 | | 2 | | | | | | | | 7 | | | 1 | 8 |
| D-1 | | | | 1 | | | | | 1 | | 9 | 4 | | |
| D-2 | | | | 13 | 7 | 8 | 1 | | 1 | 3 | 6 | 3 | | |
| D-3 | 1 | | | 52 | 26 | 35 | | | 1 | 3 | 1 | 7 | | 9 |
| D-4 | | | | | | 1 | 9 | | | | 1 | | | |
| D-5 | 5 | 1 | | 22 | 49 | 27 | 5 | | 1 | 1 | 2 | 1 | | 5 |
| E-1 | | | | | | | | 10 | 3 | 1 | | | | |
| E-2 | | | | | | | | 30 | 3 | | 2 | | 3 | |
| E-3 | | 2 | | | | | | 16 | 9 | | | | 3 | |
| E-4 | | 6 | | | 1 | | | 6 | 4 | | | | 51 | |
| E-5 | | | | | | | | 16 | 6 | | | 1 | | |
| E-6 | | | | | 2 | | | 3 | 17 | 1 | 1 | 1 | | |
| E-7 | | 6 | | 3 | 5 | | | 4 | 28 | 2 | 1 | | 2 | |
| E-8 | 1 | 14 | 1 | | | 1 | 2 | | 3 | 3 | | | | |
| E-9 | 1 | 51 | 3 | | | | | | 1 | 5 | | | | |
| E-10 | | 8 | 4 | | | | | | | | | | 1 | |
| E-11 | | | | 3 | | | 8 | | | | | | | |
| E-12 | | | | 1 | | | | | | | | | | |
| H-1 | 73 | 10 | 88 | 2 | 8 | 13 | 70 | 2 | 15 | 7 | | 2 | 11 | 70 |
| H-2 | 1 | 1 | 2 | | | 2 | 3 | 7 | 2 | 2 | 1 | | 23 | 1 |

*Source: Soil Conservation Service. 1970. General soil map, *in* Soils of Tahoe Basin. (unpub.) (Map in pocket)

**Table 5.—Soil type by percent of geomorphic unit**

| Soil type* | Geomorphic Units | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A | $B_1$ | $B_2$ | $C_1$ | $C_2$ | $C_3$ | $C_4$ | $D_1$ | $D_2$ | $E_1$ | $E_2$ | $E_3$ | $F_1$ | $F_2$ |
| Be | | | | | | | | | | | 0 | 3 | | |
| CaD | | | | 1 | 0 | 0 | 0 | | 1 | 0 | 9 | 1 | | |
| CaE | 0 | | | 13 | 7 | 8 | 1 | | 1 | 5 | 6 | 3 | | 0 |
| CaF | | | | 40 | 25 | 14 | 4 | | 1 | 1 | 1 | 2 | | 1 |
| Co | | | | | | | | | | 3 | | 6 | | |
| EbC | | | | | | | | | | 0 | 1 | | | |
| EbE | | | | | | | | | | 2 | 1 | 0 | | |
| EcE | | | | | | 0 | | | | 1 | 0 | | | |
| EfB | | | | | | | | | | 0 | 16 | 3 | | |
| EmB | | | | | | | | | | | | | | |
| Ev | | | | 0 | | | | | | 0 | 6 | 18 | | |
| Fd | | | | | | | | | | | 0 | 10 | | |
| FuD | | | | | | | | 9 | 2 | | 0 | | | |
| FuE | | | | | | | | 1 | 1 | | | | | |
| Gec | | | | | 1 | 0 | | | | 1 | 2 | 1 | | |
| GeD | | | | | | | | | | 0 | 0 | 0 | | |
| GsF | | | | 10 | | | 3 | | | | | | | |
| Gr | 0 | 1 | 0 | | | 0 | | 1 | 1 | 2 | 1 | 0 | 1 | |
| IgB | | | | | | | | | | 0 | 1 | | | |
| IsC | | | | | | | | | 0 | | 9 | | | |
| IsD | | | | | 0 | | | | 0 | 1 | 1 | | | |
| IsE | | | | | 0 | | | | 1 | | 1 | | | |
| JaC | | | | | | 1 | | | | 1 | 4 | 5 | | |
| JaD | | | | | | 2 | 0 | | | 2 | 2 | 0 | | |
| JbD | | | | | | | | | | 1 | | | | |
| JeB | | | | | | | | | | 1 | 1 | | | |
| JeD | | | | | | | | | | | 2 | | | |
| JhC | | | | | | | | 4 | 0 | 0 | 5 | | | |
| JgC | | | | | | 0 | | | 0 | 1 | 1 | 3 | | |
| JhD | | | | | 0 | | | 2 | 0 | | 0 | | | |
| JwD | | | | | | | | 21 | 3 | 0 | 2 | | 3 | |
| JwE | 0 | 2 | | | | 0 | | 16 | 9 | 0 | 0 | | 3 | |
| JwF | | 6 | | | 1 | | | 6 | 4 | 0 | 0 | | 51 | |
| Lo | 1 | | | 0 | | 0 | 0 | | | 2 | 1 | 17 | | |
| Mh | 0 | | 0 | 1 | | 0 | | 1 | 0 | 0 | 1 | 17 | | |
| MkB | | | | | | | | | | 2 | | | | |
| MkD | | | | | | 0 | | | | 1 | | | | |
| MmB | | | | | | | | | | 2 | | | | |
| MsD | 1 | | | | | 1 | | | | 4 | 0 | | | 0 |
| MsE | 0 | | | 0 | 1 | 1 | | | | 6 | 0 | | | 0 |
| MsG | 0 | | | 0 | 0 | 1 | | | | 5 | 0 | 3 | | 1 |
| MtE | 6 | | | | | 1 | 0 | | | 3 | | 1 | | 0 |
| MtG | 4 | | | | | 0 | | | | 3 | | | | 8 |
| MxE | 0 | 8 | 4 | | | | | | 0 | 0 | | | 1 | 0 |
| MxF | 6 | 3 | 10 | 0 | | | | | 7 | 1 | 0 | 1 | | |

**Table 5.—(Continued)**

| Soil type* | Geomorphic Units | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A | $B_1$ | $B_2$ | $C_1$ | $C_2$ | $C_3$ | $C_4$ | $D_1$ | $D_2$ | $E_1$ | $E_2$ | $E_3$ | $F_1$ | $F_2$ |
| Px | | | | 0 | 0 | 0 | | 0 | | 0 | 0 | | | |
| Ra | 28 | 5 | 62 | 1 | 2 | 10 | 47 | 1 | 6 | 4 | 0 | 1 | | 14 |
| RaG | | | | 0 | | 0 | | | | | | | | |
| RcF | 1 | | | 2 | 1 | 13 | 1 | | 0 | 1 | | 0 | | 4 |
| RcG | 0 | | | 0 | | 8 | 1 | | | 0 | | | | |
| RtE | | | | | | 0 | | | | 0 | | | | |
| RtF | 3 | | | 10 | 26 | 14 | 4 | | 1 | 1 | 1 | 0 | | 5 |
| RtG | 1 | | | 4 | 19 | 5 | 1 | | | 0 | | 1 | | 5 |
| Rx | 39 | 2 | 16 | 1 | 6 | 3 | 23 | 1 | 2 | 2 | 0 | | 11 | 56 |
| She | | | | 3 | | | 8 | | 0 | | | | | |
| Skf | | | | 1 | | | 0 | | | | | | | |
| Sm | 1 | 1 | 2 | | | 2 | 3 | 7 | 2 | 2 | 1 | | 23 | 1 |
| TaB | | | | | | | | 0 | 0 | | | | | |
| TaD | | | | | 0 | | | 10 | 3 | 1 | 0 | 0 | 0 | |
| TbD | | | | | | 0 | | 7 | | 0 | | | | |
| TcB | 0 | | | | | | | | | 3 | 9 | 1 | | |
| TcC | | | | | | 1 | | | 0 | 4 | 3 | | | 0 |
| TdD | 0 | | | | | 1 | | | | 6 | 2 | 0 | 3 | |
| TeE | 2 | 0 | 1 | | | 1 | | | | 6 | 1 | | | |
| TeG | 0 | 2 | | | | 0 | | | | 5 | | | 1 | 0 |
| TkC | | 0 | | | | | | | | 3 | 1 | | | |
| TmE | 2 | | | | | | | | | 1 | | | | 0 |
| TmF | 0 | | | | | | | | | 2 | | | | 1 |
| TrE | 0 | | | | | 1 | 0 | | | 0 | 1 | | | |
| TrF | 1 | 1 | | 8 | 4 | 8 | 0 | | | 0 | 1 | 0 | | |
| UmD | | 0 | | | | | | 7 | 4 | 0 | 0 | 1 | | |
| UmE | 0 | | | 0 | 2 | | | 2 | 16 | 1 | 1 | 1 | | |
| UmF | | 6 | | 3 | 5 | | | 4 | 28 | 2 | 1 | | 2 | |
| WaE | 1 | 2 | | | | 1 | 2 | | 3 | 3 | | | | |
| WaF | 1 | | | | | 0 | 0 | | | 0 | 1 | 0 | | |
| WcE | | 12 | 1 | | | | | | | 0 | 0 | 0 | | |
| WcF | 0 | 51 | 3 | | | | | | | 1 | 4 | 0 | | |

Note: 0 indicates less than 0.5%.

*Source: Soil Conservation Service. 1970. Detailed soil map, *in* Tahoe Basin soil survey area. (Unpub.) (Map in pocket)

**Table 6.—Vegetation type by percent of geomorphic unit**

| Vegetation type* | Geomorphic Units | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A | $B_1$ | $B_2$ | $C_1$ | $C_2$ | $C_3$ | $C_4$ | $D_1$ | $D_2$ | $E_1$ | $E_2$ | $E_3$ | $F_1$ | $F_2$ |
| Natural bare ground | 18 | | 8 | 0 | 1 | 1 | 5 | | | 0 | 1 | 1 | | 29 |
| Disturbed bare ground | 0 | | | | | | | | | | 0 | 1 | | |
| Herbaceous | 1 | 0 | 1 | 0 | 2 | 1 | 7 | 1 | 0 | 6 | 7 | 72 | 1 | |
| Sagebrush | 9 | | 3 | | 1 | 0 | 7 | | 1 | 2 | | 1 | | |
| Montane chaparral | 2 | 2 | 7 | 4 | 14 | 1 | 1 | 2 | 2 | 5 | 1 | 1 | 29 | 5 |
| Riparian shrub | 0 | | | 0 | | | | | | 0 | 0 | | | |
| Broadleaf | 1 | | | 4 | 0 | | 1 | | 0 | 1 | | 0 | | |
| Pine | 2 | | | 28 | 24 | 16 | 3 | 1 | 10 | 9 | 43 | 8 | | 7 |
| Pine (semi-barren) | 3 | | | 6 | | 20 | 5 | | | 1 | 1 | | | 3 |
| Mixed conifer | 1 | 24 | 12 | 42 | 31 | 23 | 1 | 60 | 31 | 26 | 33 | 3 | 43 | 8 |
| Mixed conifer (semi-barren) | | | | 2 | | 3 | 1 | 2 | 4 | 0 | 0 | | | 1 |
| Fir | 5 | 66 | 28 | 9 | 14 | 12 | 4 | 34 | 50 | 23 | 2 | 2 | 28 | 4 |
| Fir (semi-barren) | 1 | | | | | 10 | 5 | | | 5 | | | | |
| Lodgepole pine | 7 | 4 | 7 | 1 | | 1 | 2 | 0 | 1 | 14 | 12 | 10 | | 3 |
| Lodgepole pine (semi-barren) | 13 | 1 | 14 | | | 1 | | | | 2 | | | | 0 |
| Alpine | 9 | 2 | 6 | 4 | 12 | 2 | 13 | | 1 | 5 | 0 | | | 1 |
| Alpine (semi-barren) | 26 | | 6 | | 0 | 9 | 45 | | | 1 | | | | 24 |

Note: 0 indicates less than 0.5%.

*Source: Tahoe Regional Planning Agency and USDA Forest Service. 1971. Vegetation types *in*, Vegetation of the Lake Tahoe Region—A guide for planning. (Map in pocket)

This publication is one of a group issued jointly by the Tahoe Regional Planning Agency and the USDA Forest Service. Each publication describes and inventories a natural resource or other characteristic that is significant to the total environment of the Lake Tahoe Region; it attempts to show the hazards incidental to improperly planned development of the area and to provide information helpful in designing controls that must be implemented if the scenic beauty of the Lake Tahoe Region is to be preserved and its other natural resources are to be conserved. These publications are not exhaustive treatises of their subjects, but they highlight the known significant information and data useful in the planning effort underway. Subjects of publications in this series are:

Climate and Air Quality of the Lake Tahoe Region

Cultural and Historical Significance of the Lake Tahoe Region

Land Resources of the Lake Tahoe Region

Fisheries of Lake Tahoe and Its Tributary Waters

Geology and Geomorphology of the Lake Tahoe Region

Hydrology and Water Resources of the Lake Tahoe Region

Limnology and Water Quality of Lake Tahoe and Tributary Waters

Recreational Resources of the Lake Tahoe Region

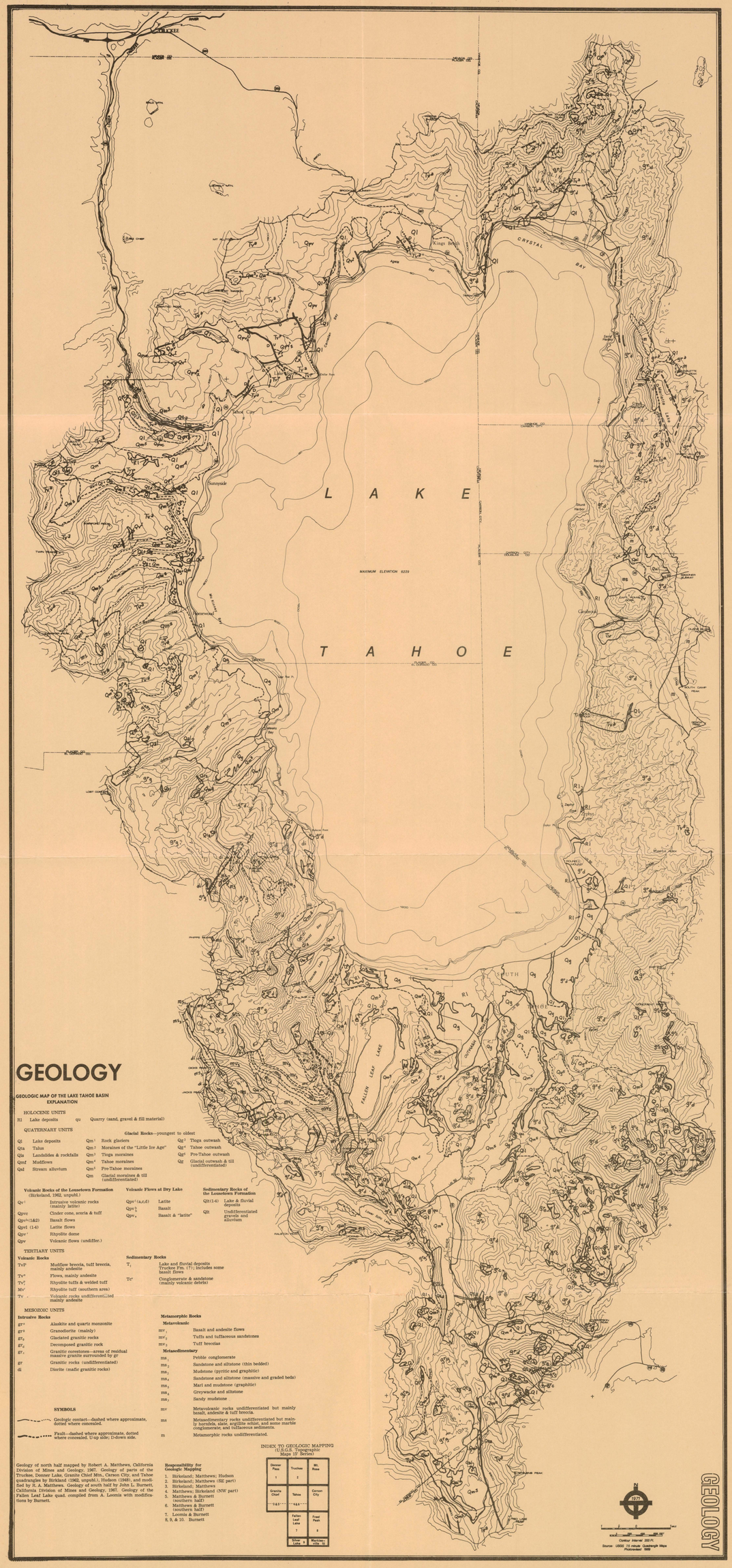
Wildlife of the Lake Tahoe Region

Soils of the Lake Tahoe Region

Vegetation of the Lake Tahoe Region

Scenic Analyses of the Lake Tahoe Region

Because of the heavy expense of publication and because these reports are designed chiefly for use by planners, supplies are not available for general public distribution.


L A K E
T A H O E
MAXIMUM ELEVATION 6229
CRYSTAL BAY
Kings Beach
Tahoe City
Sunnyside
Homewood
Tahoma
SOUTH
FALLEN LEAF LAKE
Cascade
Emerald Bay
Meeks Bay
Rubicon Point
Sugar Pine Pt.
Ward Creek
Dollar Point
Carnelian Bay
Agate Bay
Dollar Hill
Tahoe Vista
Kings Beach
Brockway
Crystal Bay
Incline Village
Sand Harbor
Glenbrook
Zephyr Cove
Round Hill
Stateline
Lake Tahoe Airport
Meyers
Christmas Valley
Echo Summit
Echo Lake
Upper Truckee River
Angora Peak
Mt. Tallac
Dicks Peak
Jacks Peak
Maggies Peak
Rubicon Peak
Ellis Peak
Pyramid Peak
Desolation Wilderness
Mount Tallac
Freel Peak
Job's Sister
Job's Peak
Monument Peak
Genoa Peak
Kingsbury Grade
Lake Tahoe Blvd.
Pioneer Trail
Fallen Leaf Lake Road
Emerald Bay Road
Tahoe Meadows
Tahoe Keys
Tahoe Keys Blvd.
Lake Tahoe Golf Course
Lake Tahoe Country Club
Lake Tahoe Nevada State Park
Lake Tahoe Basin
Lake Tahoe Nevada State Park
Lake Tahoe Blvd.
Lake Tahoe Airport
Lake Tahoe Golf Course
Lake Tahoe Country Club
Lake Tahoe Nevada State Park
Lake Tahoe Basin